A STUDY OF PRE-SERVICE SCIENCE TEACHERS' PEDAGOGICAL USE OF MULTIPLE REPRESENTATIONS DURING LESSON PRESENTATIONS

by

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DECLARATION

By submitting this thesis/dissertation electronically, I, Christina Elizabeth Maree, declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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ABSTRACT

The science teacher has to have the pedagogical skills to be able to explain any concept by using multiple representations to optimise learning for their learners and develop their abilities to transfer knowledge. Communicating verbally, displaying information by means of tables and graphs, the use of text, diagrams, symbols, models and simulations are amongst these representations that are used to communicate the body of scientific knowledge about phenomena that occur in the natural world. This study is focused on the way in which pre-service science teachers (PSSTs) use multiple representations during lessons in the classroom as part of their pedagogical repertoire. The way in which these are constructed by the PSSTs in complex classroom settings, as well as how they select, use and translate between representations is the problem I address in this study.

The main research question that the study addresses is "How do pre-service science teachers use multiple representations as a pedagogical tool to explain science concepts during their lessons?". A concurrent dependent mixed-methods design was adopted in this study, more specifically taking on a *QUAL + quan* design driven by the video-recorded qualitative data collected. The findings show that for a sample of 167 PSSTs enrolled in initial teacher education programmes at university, the predominant modes used in Physics were Non-specialist Words, Graphical representations and Expert Words. In Chemistry it was predominantly Non-specialist Words, Experimental representations and Expert Words. The modes that were most prominent overall were Non-specialist Words and Expert Words. PSSTs showed similar levels of competence and fluency in using or not using Experimental representations, Non-specialist Words and Expert Words, which was not the case for Graphical representations and Symbolic representations. Overall PSSTs showed similar levels of competence and fluency across all representational modes combined when presenting Physics and Chemistry lessons. None of the most frequently observed fluency code combinations for Physics and Chemistry included Experimental representations. Less than 5% of PSSTs showed high levels of representational fluency in all five representational modes in Physics, and only about 6% PSSTs showed representational fluency in all five representational modes in Chemistry. The findings point towards statistically significant differences in Non-specialist and Expert Words used. Significantly more PSSTs used Non-specialist Words at a high level of competence and fluency compared with those who use Expert Words. The overall findings of the study indicate that the PSSTs did not show adequate levels of competence and fluency when teaching science with the help of MRs.

KEY TERMS: Multiple Representations (MRs); Pedagogical Content Knowledge (PCK); Competence; Fluency; Scientific Literacy; Curriculum; Scientific Community of Practice (SCoP); Mixed-methods Study

OPSOMMING

Die wetenskap onderwyser moet die pedagogiese vaardighede besit om enige konsep te verduidelik deur veelvuldige voorstellings te gebruik sodat leer en kennis oordrag optimaal by hul leerders kan plaasvind. Verbale kommunikasie, voorstelling van inligting deur tabelle en grafieke, gebruik van teks, diagramme, simbole, modelle en simulasies is onder andere van die voorstellings wat gebruik word om die liggaam van wetenskaplike kennis te kommunikeer na aanleiding van verskynsels in die natuur. Hierdie studie fokus op die manier hoe voordiens wetenskaponderwysers (VWOs) veelvuldige voorstellings gebruik tydens lesse in die klaskamer as deel van hul pedagogiese repertoire. Die manier hoe bogenoemde gekonstrueer word deur VWOs in komplekse klaskamer instellings, sowel as hoe hul voorstellings selekteer, gebruik en transleer tussen voorstellings, is die probleem wat ek aanspreek in hierdie studie.

Die hoof navorsingsvraag wat die studie aanspreek is "Hoe gebruik toekomstige wetenskap onderwysers veelvuldige voorstellings as 'n pedagogiese hulpmiddel om wetenskap konsepte te verduidelik tydens lesse?". Die gemengde metodes ontwerp wat die studie aangeneem het was 'n gelyktydige afhanklike ontwerp, meer spesifiek 'n *KWAL + kwan* ontwerp gedrewe deur die video opname kwalitatiewe data wat ingesamel is. Die bevindings toon dat vir 'n steekproef van 167 VWOs wat ingeskryf was vir aanvanklike onderwysopleidingsprogramme aan die universiteit, die oorheersende modusse in Fisika was Nie-Spesialis Woorde, Grafiese voorstellings en Kenner Woorde, terwyl dit in Chemie Nie-Spesialis Woorde, Eksperimentele voorstellings en Kenner Woorde was. Die modusse wat algeheel die mees prominent gebruik was is Nie-Spesialis Woorde en Kenner Woorde. VWOs het soortgelyke vlakke van bekwaamdheid en vlotheid getoon in die gebruik of die gebrek aan gebruik in Eksperimentele voorstellings, Nie-Spesialis Woorde en Kenner Woorde, wat nie die geval was met Grafiese voorstellings en Simboliese voorstellings nie. In die algemeen het VWOs soortgelyke vlakke van bekwaamdheid en vlotheid getoon oor al die voorstellingsmodusse heen gekombineerd wanneer hul Fisika en Chemie lesse aanbied. Geen van die mees gereelde waargenome vlotheid kode-kombinasies in Fisika of Chemie het Eksperimentele voorstellings ingesluit nie. Minder as 5% van VWOs het hoë vlakke van voorstellingsvlotheid in al vyf voorstellingsmodusse in Fisika getoon, en slegs ongeveer 6% van die VWOs het hoë vlakke van voorstellingsvlotheid in al vyf voorstellingsmodusse in Chemie getoon. Die bevindings toon statistiese beduidende verskille tussen die gebruik van Nie-Spesialis Woorde en Kenner Woorde aan. Beduidend meer VWOs het Nie-Spesialis Woorde op 'n hoë vlak van bekwaamdheid en vlotheid gebruik teenoor die wat Kenner Woorde gebruik. Die algehele bevindings van die studie dui daarop dat VWOs nie voldoende vlakke van bekwaamdheid en vlotheid toon wanneer hul wetenskap onderrig met behulp van veelvuldige voorstellings nie.

SLEUTELWOORDE: Veelvuldige voorstelings; Pedagogiese Inhoudskennis (PIK); Bekwaamdheid; Vlotheid; Wetenskaplike Geletterdheid; Kurrikulum; Wetenskaplike Gemeenskap van Praktyk; Gemenge Metodes Studie

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CHAPTER 1: INTRODUCTION

In science education the teaching and learning process is characterized by external representations which the teacher might use and internal representations that the learner would likely use to make sense of the content matter under discussion. The teacher's verbal explanation could be accompanied by a diagram whilst the learners must process and comprehend the information (Opfermann, Schmeck, & Fischer, 2017). This study is focused on the way in which pre-service science teachers (PSTs) utilise multiple representations (MRs) during lesson presentations. Although many studies on MRs have been done at an international level, there is a need to examine how PSTs use MRs in the South African context. In the next few sections in this chapter I will provide a background and overview of the study.

1.1 Motivation and Background

My interest to conduct this study stems from my involvement with the Natural Sciences (NS) Education students enrolled in a Bachelor of Education (BEd) programme at university. For the past five years I have been a part-time lecturer of the NS module in specifically the Physics and Chemistry components of the module. For the past three years I have also been evaluating lessons during Micro-teaching and Practice sessions at Stellenbosch University and placement schools respectively. My interest in the topic of teachers' use of multiple representations is further fueled by the fact that, together with another partner, we have started a business in 2017 where we provide extra classes to primary school, high school and post-matric learners of all academic levels in the topics of Mathematics, Natural Sciences and Physical Sciences. My focus in the business is on Natural and Physical Sciences. I have also in the past been involved in giving extra Physical Sciences classes at two High Schools located in previously disadvantaged areas. I spent three years working at these two schools. This has, together with the abovementioned experiences, led to one of my biggest motivations to conduct this study at a local level – the poor state of science education and inadequate teachings of some science teachers in South Africa which I elaborate upon later in this chapter.

1.1.1 Teaching Science and Multiple Representations

Maree and Edwards (2019, p. 1) stated that the teaching of science requires an "array of strategies or methods to convey the meaning of concepts or phenomena", while the learning of science includes the "development of a common, shared understanding of scientific concepts". Daniel, Bucklin, Leone and Idema (2018, p. 3) suggested that various representations in science can be used to organise information, display data and to promote the generation of shared and constructed understanding and meanings of scientific phenomena. Communicating verbally, displaying information by means of tables and graphs, the use of text, diagrams, symbols, models and simulations are amongst these representations that are used to communicate the body of scientific knowledge about phenomena that occur in the natural world. It is therefore important that science students be introduced to the various ways in which these phenomena are represented in order that they develop a good understanding about them. These phenomena, and the different modes it can be represented with, can also range from the straight forward and simple to the very complex. In education, the challenge is for the science teacher to have the pedagogical skills to be able to explain any concept by using multiple representations and to select the relevant representational mode(s) as to optimise learning for their learners and develop their abilities to transfer knowledge. To even start to understand and know a specific concept one should at least have some form of mental representation of it (Stenning, 1998). Many scientific concepts are abstract and scientists develop different models to explain these concepts. A simple example is that of the atom which requires an understanding of particles at the micro-level. Scientists have produced different models of the atom since the time of the Greek Democritus up to the Bohr-model, which we still use today. Shulman (1986, p. 9) identified all of this in the notion of Pedagogical Content Knowledge (PCK):

> "… I include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations- in a word, the ways of representing and formulating the subject that make it comprehensible to others."

Maree and Edwards (2019) concluded from this statement that key to the development of the repertoire of a science educator lies the use of MRs to promote understanding of subject disciplinary knowledge. Tang, Degado and Moje (2014, p. 306) mentioned that "representations are artefacts that symbolize an idea or concept in science (e.g., force, energy, chemical bonding) and can take the form of analogies, verbal explanations, written texts, diagrams, graphs, and simulations". All of these different representations are used as methods of communicating science visually. Daniel et al. (2018) noted that the success of these visual communications is dependent on the receiver's sense-making abilities in a manner that is consistent with the understanding and thinking in the science community. In order for us to understand and explain some phenomena that can be observed macroscopically, we must refer to what is happening microscopically.

In chemistry, for example, the rusting of metal is observable at a macro-level when one can see the formation of rust, which is iron oxide. A teacher can produce a word equation as well as a balanced chemical equation after the student has observed the reaction. A diagram can also be used to represent what happens at the micro-level in terms of the changes that the iron and oxygen undergo. In physics, the concept of an electric current is evident when looking at a light bulb that shines when connected in a closed circuit with a dry cell. Understanding how current flows in the wire requires a model of what a metallic conductor looks like and how a flow of charge may occur. These two examples are illustrated in the diagrams below (Figure 1.1).

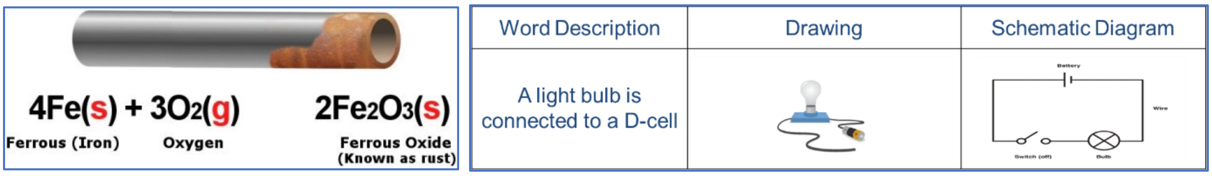


Figure 1.1: Various modes of representing different concepts in science education (chemistry and physics)

It is evident from these two examples that different modes of representing the same concept may help develop and foster understanding when explaining scientific phenomena. It is therefore a necessary pedagogical tool which science teachers all over the world can use to better develop certain scientific concepts. Even more so it could be used by teachers in South Africa to potentially overcome the language barriers in the classroom, and use a universal scientific language to communicate science concepts.

1.1.2 The State of Science Education in South Africa

In South Africa there are numerous factors that contribute to the poor state of science education, especially when taking into account the influence that the apartheid era had on the under-development of certain groups' human potential (Mji & Makgato, 2006). According to De Beer (2016) there are too few quality and adequately qualified science teachers in South Africa and thus science teachers' "under-developed pedagogical content knowledge" contribute tremendously to the situation of poor science education in the country. He also mentions the shortcomings in the form of lacking teaching resources provided to and by the schools (De Beer, 2016). Mji and Makgato (2006) agrees with this and adds that outdated teaching practices, overcrowded classrooms, lack of motivation and interest, content knowledge and understanding, inefficient or no laboratory usage, non-completion of the syllabus, parental roles and language also contributes to the problem. The origin of most of these factors can be traced back to the socio-political issues South Africa has faced in the past, especially the language problem. Webb (2017) mentioned that language is always political and I believe that this contributes to problems experienced in science education in more than just one way. In a study conducted by Prinsloo, Rogers and Harvey (2018) it was found that more than 50% of the overall effect on Science scores in South African classrooms can be attributed to language either directly or indirectly. Science as a discipline has a very specific language and we can refer to this as a part of scientific literacy. A good science teacher should first of all be comfortably aware of this scientific language and be able to use this properly to educate learners. Since a language does not only include words, but also mannerisms, expressions and visual aids, I believe that multiple representations in science are an integral part of scientific literacy especially when the purpose of the teacher and student interaction is to participate and integrate into a science community of practice.

There are a wide range of languages spoken in South Africa and teaching and teacher training mostly takes place in the language of the minority groups. I therefore believe that multiple representations in science education can play a major role in making the language of science universal and accessible for learners who are being schooled in their second or third language. A good science teacher should then have the pedagogical content knowledge to use multiple representations to communicate abstract science concepts. Mammino (2014) referred to this as a language-visualisation interplay (LVI) while Larsson and Jakobsson (2019) referred to this as a hybrid of languages. According to Lee (2013, p. 2) Science is a language intensive practice where "students speak and listen as they present their ideas or engage in reasoned argumentation with others to refine their ideas and reach shared conclusions". This again reminds one of the importance of language when identifying and integrating into a science community of practice. He added that learners develop their models and explanations when they read, write, view and visually represent concepts. This again indicates the essence of language in science (Lee, 2013). Consistent with this Stutchbury, Banks and Dewan (2016, para. 5) mentioned that "thought requires language and language requires thought". Other than the language problems teachers and learners face in science classrooms in South Africa, they are also confronted by a curriculum built from standards-based assessments.

According to DeBoer (2000) a curriculum that is developed with standards-based assessment in mind may potentially inhibit the autonomy as well as the creativity of the teachers and the learners that engages with the curriculum – in my opinion this is exactly what is happening in South African science classrooms. As an antithesis to this approach DeBoer (2000) mentioned that teachers and learners can have opportunities to experiment freely with pedagogical approaches and teaching and learning will take place all the while acknowledging the strengths and the interests of the learners when a curriculum consists of broadly stated goals instead of a restrictive set of guidelines. When looking at the aims of the South African CAPS curriculum a few points stand out which directly confirm implications of DeBoer's comments above. The general aims of the South African School Curriculum as well as the specific aims for Natural Sciences and Physical Sciences can be found in Addendum A.

In Addendum A under **General Aims of the South African Curriculum** the CAPS curriculum states that it (a) "…gives expression to the knowledge, skills and values worth learning in South African schools. This curriculum aims to ensure that children acquire and apply knowledge and skills in ways that are meaningful to their own lives.". The question that comes to mind is who are the ones deciding which knowledge, skills and values are worth learning – do the learners also get to contribute to this? It also implies that learners do not create or play an active role in knowledge development as they only acquire and apply these.

The CAPS document also states that it was developed (c) on the following principles (amongst others):

- Active and critical learning: encouraging an active and critical approach to learning, rather than rote and uncritical learning of given truths;
- High knowledge and high skills: the minimum standards of knowledge and skills to be achieved at each grade are specified and set high, achievable standards in all subjects;

These two consecutive bullets are directly contradicting one another, because by setting out the specific content and skills that the learners MUST know through their engagement with the curriculum and formally testing of it afterwards, strongly encourages rote learning of the CAPS given and prescribed truths.

In Addendum A under **Specific Aims of Natural Sciences Curriculum (Senior Phase)** one can also see the following:

> Specific Aim 2: 'Knowing the subject content and making connections'
>
> <u>Learners should have a grasp of scientific, technological and environmental knowledge and be able to apply it in new contexts.</u>
>
> <u>The main task of teaching is to build a framework of knowledge for learners and to help them make connections between the ideas and concepts in their minds – this is different to learners just knowing facts. When learners do an activity, questions and discussion must follow and relate to previously acquired knowledge and experience, and connections must be made.</u>

The first underlined phrase implies that learners do not have their own framework of knowledge and that they can't make connections between ideas and concepts (abstract and concrete) – again learners assume a relatively passive role in their teaching and learning. The second underlined phrase implies that it is only after learners engage with an activity (prescribed by the CAPS document) that questions and discussions are allowed.

In Addendum A under **Specific Aims of Physical Sciences Curriculum (Further Education and Training Phase)** it states that the "…purpose of Physical Sciences is to make learners aware of their environment and to equip learners with investigating skills…".

In stating this as a purpose of the subject it is insinuated that learners are not aware of their environment and that they do not possess the necessary skills to investigate a phenomenon or concept.

The above comments on the aims as set out by the science curriculum document show that the intentions of the curriculum and the actual execution of and engaging with it may be conflicting as experienced by teachers and learners. Unfortunately this study does not put me in a position to change the curriculum, so instead I propose that teachers must be equipped to install autonomy in the science classroom and encourage creativity even if teaching and learning is expected to take place within the restrictions of the CAPS document and particularly against a South African setting where language issues pose major challenges. The literature review in Chapter 2 elaborates on how the use of multiple representations in the science classroom may provide a solution to this conundrum and why pre-service teachers should be able to include MRs as part of their pedagogical repertoire. In order for teachers to use these tools, they should demonstrate representational competence and fluency.

1.2 Statement of the problem

Tippett (2011) argued that representational competence is a key component of science literacy, and it includes the appropriate use of representations to conceptualise and communicate about science concepts. However, the author proposed that much more research is required on learning *with* rather than *from* representations, as well as learners' constructions thereof. Before we can investigate the learning with MRs in science, we must make sure that our teachers moving into the system are equipped to teach with MRs. The complexities inherent in the classroom setting must also be taken cognizance of. Teachers must have the ability to scaffold learners' ability to translate between representations even when they have a large repertoire of representations (Moore, Guzey, Roehrig & Lesh, 2018). It has also been found that making connections in science is a representational competence that learners struggle to master (Rau, 2017), and is more often referred to as representational fluency, which again indicates the importance of the science teacher being able to facilitate these connections to be made.

Studies have shown that in physics problem-solving pictorial representations are effective for concept formation (Botzer & Reiner, 2005). Representations are useful tools for constructing and communicating understanding when individuals are integrated into a community of practice. Those with little representational competence rely on surface features whereas those with more skill use a variety of representations (Kozma & Russell, 2005).

In the light of the above, which shows that a good science teacher has to have a range of pedagogical skills in order to explain and facilitate concepts in science education, this study is focused on the way in which pre-service science teachers (PSSTs) use multiple representations during lessons in the classroom as part of their pedagogical content knowledge. The way in which these are constructed by the PSSTs in complex classroom settings, as well as how they select, use and translate between representations is the problem I address in this study. This is a gap that I have identified as is evident from the literature, especially in a South African setting.

1.3 Purpose of the study

The purpose of this study is to explore the representational competence and fluency of pre-service science teachers as they develop and execute their pedagogy in science education. Representational competence is static and refers to the ability to use and way of using different modes of representation, while representational fluency is a dynamic process referring to the navigation within and between different representational modes (Daniel et al., 2018).

This study is broadly located within the development of science teachers' pedagogical content knowledge (PCK) and their use of multiple representations as a pedagogical tool in the science classroom. PCK is thought to be an amalgam of a teacher's pedagogy and understanding of content such that it influences their teaching in ways that will best engender learners' learning for understanding (Berry et al., 2008). The study was conducted against a socio-cultural backdrop, underpinned by a social constructivist perspective, and it is thus believed that teaching and learning with MRs contributes to the PCK of the teacher and that MRs too can act as mediators to construct knowledge and deeper understanding, as well as to negotiate meaning when used to communicate to members of a specific community of practice.

1.4 Theoretical Framework

A socio-cultural framework argues that learning and knowing should be seen as a process of enculturation into the discursive practices of science (Lave and Wenger, 1991). Sociocultural theory begins with the premise that children, in their development, reconstruct the cultural knowledge from the previous generations of communities they belong to (Vygotsky, 1981). I believe that even though the real world exists, it is meaningless if no attempt is made to interpret and understand it through meaning making processes by interacting with the real world and the meaning making processes of other human beings. John-Steiner & Mahn (1996) emphasised that there is an interdependence between the social processes and the individual processes in the construction of knowledge – thus reality is created by individuals in groups. The power of interaction lies in the agreement of certain interpretations in a given social group or community of practice (Bozkurt, 2017). The Zone of Proximal Development (ZPD) as proposed by Vygotsky describes the distance between independent learning and mediated or facilitated learning in collaboration with more capable others in a specific community (Mutekwe, 2018). This points towards Vygotsky's emphasis on interactive learning activities as an approach to draw on diverse contexts and sociocultural backgrounds of members of a group. Knowledge is thus mediated and co-created socially, followed by learning at an internal and individual level as a result of collaborative knowledge creation (Churcher, 2014).

Learning through a social constructivist lens thus largely refers to participation in interaction with the members of a community where the community and the context of the community is integral to what is learned (Dudley-Marling, 2012). A teacher should, when teaching from a social constructivist perspective, acknowledge that knowledge is constructed and established in groups through interaction and language (Au, 1998), but also that learners are able to perform certain tasks on their own, while other knowledge constructions can only be achieved through this social interaction with more experienced others (teachers, peers or other members of a Community of Practice or CoP) (Mutekwe, 2018). Lev Vygotsky viewed a mediator not only as human (peer, parent or teacher for instance), but acknowledged that a mediator could also be the tool(s) used in a teaching and learning process to enhance a learner's understanding of a concept at play. Vygotsky lists a few mediators such as other human beings, materials, psychological tools as well as semiotic tools to translate cognitive functions to higher levels (Mutekwe, 2018). Social interaction and language usage is thus inseparably entwined and dependent on one another for growth in either one – and it is through the combination of these two that we can establish effective communication in the South African classroom in order for us to start to embrace the diversities we find in these specific classrooms. One of these measures of effective communication in specifically Science Communities of Practice (SCoPs) may be the use of multiple representations to effectively communicate (explain and understand) specific scientific concepts.

Literature in science education argues the need for learners to actively construct representations in order for them to become competent in scientific practices and to learn through participating in the reasoning processes of science (Ford and Forman, 2006). The research questions that follow have been based on the literature which argues that a good science teacher will use multiple representations to communicate and explain science concepts to their learners, and therefore there is a need to look at the use of these MRs as part of pre-service science teachers' pedagogy during their formal training.

1.5 Research Questions

The main research question that I wish to address in this study is as follows:

How do pre-service science teachers use multiple representations as a pedagogical tool to explain science concepts during their lessons?

The following sub-questions will guide the study:

a) What are the different modes of representation that pre-service science teachers explicitly use during lessons?

b) Is there a statistically significant difference between pre-service science teachers' use of multiple representations as well as their level of representational competence and fluency in Physics and Chemistry?

c) How do pre-service science teachers engage in translation activities (integration across different modes of representation) in order to explain a specific scientific concept?

d) Is there a statistically significant difference in how pre-service science teachers use every day literacy compared to scientific literacy?

In asking these questions I attempt to investigate and interpret the multiple representational competence and fluency PSSTs demonstrate during practice teaching lessons.

1.6 Significance of the Study

Hitting very close to home, the following poem was written by a Navajo child who describes a classroom as she experienced it – and it reminds of the average South African science classroom:

> "Our teachers come to class,
>
> And they talk and they talk,
>
> Til' their faces are like peaches,
>
> We don't;
>
> We just sit like cornstalks."

(Cazden, 1976, p. 74)

The focus on the use of MRs by student science teachers can potentially help to gather information on the pedagogical content knowledge (PCK) of these pre-service science teachers. This information may in turn provide us with more information on some of the mentioned factors that contribute to the poor state of science education in South Africa and how we can improve or adapt teacher training endeavors. I believe that quite a lot of research has been done in South Africa on the factors that contribute to the poor state of science education, but very little research has been done to look at pedagogical tools that could potentially address these problems and their causes in a South African context. Since language, adequately qualified teachers and teaching methods are some of the biggest contributing factors; it is of relevance to look at the use of MRs by soon to be professionally qualified science teachers as part of their PCK.

This study may hold significance to inform different parties in South Africa including various teacher training institutions or programmes, department of education policies and approaches to the curriculum, educational reform efforts, schools, teachers as well as other educational researchers.

1.7 Research Methodology

This study was designed to explore and investigate the use of multiple representations by pre-service science teachers during lesson presentations. This study is underpinned by a social constructivist perspective. A constructivist approach deems reality as a collection of interpretations and when applied to social psychology (social constructivism) reality is viewed as the social consensus of the real world between people and thus requires a more qualitative approach (Patel, 2015). This perspective then urges the researcher to actively interact with the research participant and the setting as to create meaning (Kim, 2014). However, it is argued in the literature that a study which aims to better understand a social phenomenon, such as a teaching repertoire, will have increased understanding when conducting the investigation through a mixed methods research approach (Sammons & Davis, 2016). They also propose that the flexibility in a mixed methods study is beneficial when investigating intricate educational matters.

It is in line with this view of the social constructivist researcher that the study aims to collect data through a mixed methods approach, as this is seen as the "third methodological paradigm" and "is particularly important for the investigation of complex social and behavioural phenomenon" such as the PCK of teachers (Sammons et al., 2016, p. 13). Using such mixed methods may increase the coherence and insightfulness of a study and the authors argue that a well-planned mixed methods study may be useful to novice researchers to encourage creativity and flexibility.

According to Sammons et al. (2016) there is a history of the use of mixed methods in educational research and has led to the development of many educational principles and policies. They argue that the appeal of using mixed methods in educational research lies in the fact that one can combine stories and numbers and represent a synergy between the two in the findings. Sammons et al. (2016)

describes three different mixed methods studies that was conducted to investigate teachers' pedagogical effectiveness and argues that it is evident from these studies that the purpose and the research questions drive the mixed methods approach of each study.

The mixed methods approach was thus chosen due to the aim of the study to investigate PSTs competence and fluency in the use of MRs during practice teaching sessions, where both competence and fluency could be investigated in more depth and breadth when looking at the data through a quantitative and a qualitative lens combined instead of just one perspective. Johnson, Onwuegbuzie and Turner (2007) positions the mixed method approach in between quantitative and qualitative research, where both extremes are respected while compromises are made to eventually get to a practical and achievable way of approaching research problems combining quantitative and qualitative. Johnson et al. (2007) views a mixed method approach as applicable to all various research paradigms and theoretical frameworks as to create breadth, depth and corroboration in the study.

The mixed methods design this study undertook was the form of a concurrent dependent design (Schoonenboom & Johnson, 2017; Fischler, 2014; Creswell & Clark, 2017), more specifically taking on a *QUAL + quan* design, where a concurrent design is driven by the qualitative data collected. The nature of the concurrent dependent design is to collect the data, in this case the video recorded lessons, and coding the data as a qualitative analysis as set out in Section 3.6.1. The coded data was analysed quantitatively as to support the qualitative data. The purpose of this design is to integrate quantitative results and qualitative results obtained from qualitative data in order for the researcher to provide a more comprehensive reflection of the study's results. In this study there is only one point of integration, thus resulting in a simple mixed methods design (Schoonenboom & Johnson, 2017). Even though this approach incorporates the quantifying of the qualitative data, the shift to constructivism takes place when analysing and interpreting data qualitatively (Fischler, 2014).

This study will be a fixed mixed method approach, meaning that the qualitative and quantitative methods are predetermined and planned according to the needs of the research questions at hand. I believe that without the addition of qualitative findings the quantitative findings would be barren and dull. The final step of the fixed concurrent dependent mixed method design of this study was for quantitative results to be interpreted, together with the qualitative data, and finally a discussion on the extent to which the qualitative explains the quantitative took place (Creswell & Clark, 2017). The diagram below gives a systematic indication of the study's mixed methods approach.

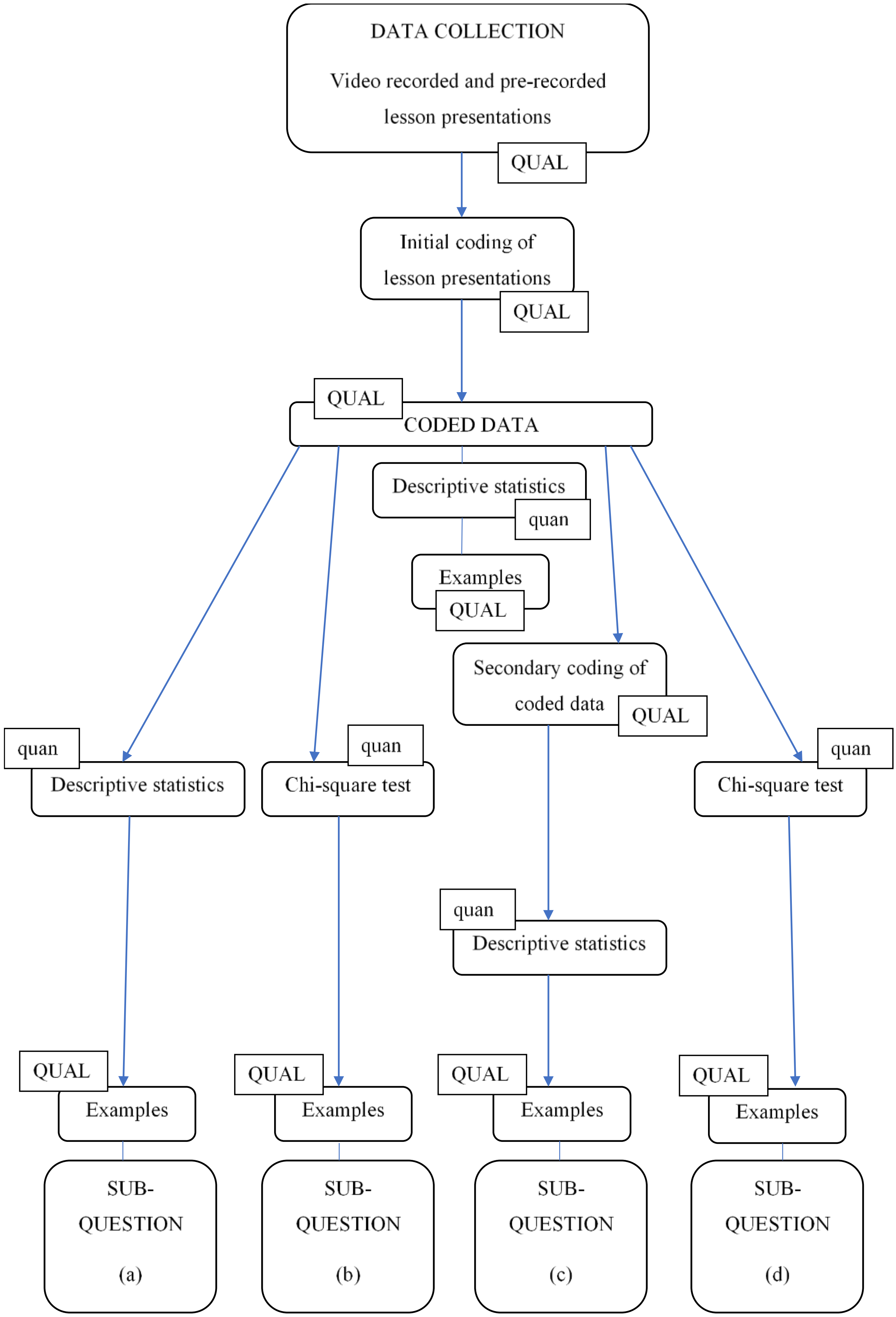


Figure 1.2: Flow diagram of mixed methods approach for this study

Classroom observation video recordings were conducted by myself during the lessons presented by the pre-service teachers at Stellenbosch University and the selected schools where they were placed during their practice teaching experience. The pre-recorded video lesson presentations that were analysed made up a part of the portfolio of evidence the pre-service science teachers had to hand in during the course of their studies for the enrolled module. Lessons conducted on topics classified as Chemistry or Physics related concepts according to the CAPS curriculum were identified using the CAPS curriculum as reference framework and then analysed for the purpose of this study. The setting of this study can be described as investigating how students at Stellenbosch University enrolled in either a Natural Sciences module in a Bachelor of Education program or a Physical Sciences module in a Post Graduate Certificate in Education use multiple representations (MRs) to explain science concepts. Ethical clearance and pre-service teacher consent was obtained to conduct this study.

An initial qualitative analysis in the form of content analysis was conducted where each mode was coded with a value (0 = no evidence; 1 = low level; 2 = medium level; 3 = high level) as set out in Table 3.5 (Chapter 3) and these values were captured in a spreadsheet. No attempt at any representation was indicated as zero (0). The frequency of each level for a specific representation (graphical, experimental, symbolic, non-specialist words, expert words) was tallied and expressed as a percentage (Tables 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6). An example of how a lesson was coded can be found in Addendum K.

A Secondary coding was done on the results of the first codes in an attempt to investigate the fluency between different representational modes for physics and chemistry respectively. The codes assigned in this step were for the different modes of representation as indicated in Table 3.6. For those lessons that qualified (as set out in Chapter 4) the secondary codes were combined in the order G, E, S, NS, X if present (Addendum M). The different code combinations were identified and tallied for Physics and Chemistry and expressed as a frequency of occurrence (Tables 4.19 and 4.20).

As part of the qualitative analyses the Chi-Square Test was used in Section 4.4 to determine the statistical significance of the difference between representational competence between Physics (n=83) and Chemistry (n=84). The same analysis was completed for each one of the Representational Modes (Graphical; Experimental; Symbolic; Non-specialist Words; Expert Words).

The Chi-Square Test was again conducted in Section 4.6 to determine the statistical significance of the difference between representational competence between the Non-specialist Words and Expert Words representational modes. The same analysis was completed for Physics (n=83), Chemistry (n=84) and Physics and Chemistry combined (n=167).

Throughout the study, and as set out in Figure 1.2, descriptive statistics in the form of percentages and frequency of occurrence were used to describe the results obtained from the coding phases in the study in an attempt to interpret these results in such a way that could potentially shed light on the research sub-questions and finally the main question the study aims to answer.

1.8 Delimitations of the Study

The study examines how students at Stellenbosch University enrolled in a Natural Sciences module in a Bachelor of Education program and Physical Sciences module in a Post Graduate Certificate in Education use multiple representations (MRs) to explain science concepts. These students will ultimately teach Natural Sciences in the Senior Phase (Grade 7 – 9) or Physical Sciences in the Further Education and Training phase (Grade 10 – 12) and would need to develop their skills as they engage with the curriculum in a science teaching classroom. All students enrolled for these modules were approached to participate in the study, while only the ones who agreed to participate and signed the consent forms were contacted to arrange for data collection dates. A distinction was made between Physics and Chemistry during the presented lessons and data analysis as the pre-service teachers had to choose a specific topic that could only be relevant to either physics or chemistry as set out in the CAPS curriculum of South Africa. Of the participants who agreed to participate, those who chose to present lessons from the Biology section of the Natural Sciences CAPS curriculum were eliminated as such data cannot be classified as Chemistry or Physics. The data will be collected at the university during micro-teaching lessons and practice teaching sessions at schools located in surrounding areas in close proximity to the university.

1.9 Limitations of the Study

It is necessary for me to acknowledge the general assumptions, and thus limitations, of the proposed study. Firstly, I assume that these pre-service science teachers will make use of MR during their lessons when asking the secondary research questions. It is however very unlikely that a teacher would not use any other mode of communication (representation) other than spoken text. Secondly, I must be acutely aware of my own interpretation and understanding of multiple representations in science as to not be judgemental about aspects of the use of MR. These aspects may include but are not limited to: successful use thereof and whether or not, and if so, how learning took place during the lessons. This will help to focus the study as these aspects are not applicable in the proposed study and may influence my subjective view when taking notes during the lessons and coding the data. I should also acknowledge the fact that PCK is generally viewed as either transformative or integrated and that personal perspective could play a role in the interpretation of the use of MR as part of the pre-service teachers PCK. Since the data will be collected at Stellenbosch University and at schools located in surrounding areas in close proximity to the university under discussion, this study will not be a completely accurate reflection of pre-service science teachers in South Africa as a whole, but merely a specific region in South Africa. However, all these lessons will be presented by pre-service science teachers with diverse backgrounds, to learners from diverse backgrounds at schools located in diverse communities – thus being representative of the diversity of South Africa to some extent. However, the data collected could not be seen as being representative of the diversity of the content of the Science CAPS curriculum since only some of the topics in the curriculum was presented during the video recorded lessons.

1.10 Definitions of Key Terms

I identified a few key terms that are repeatedly used throughout the literature review, methodology, results and discussions in this study and these outline the central themes of the study. Some of these terms have various definitions when looking at the literature and depending on which research perspective is taken. Some of these various definitions are addressed in the following chapters, however, the definitions below give a clear perspective on how I accepted and interpreted the key terms:

Multiple Representations (MRs) : Various external modes of representing scientific concepts such as communicating verbally, displaying information by means of tables and graphs, the use of text, diagrams, symbols, models and simulations are amongst these representations.

Pedagogical Content Knowledge (PCK) : An amalgam of a teacher's pedagogy and understanding of content such that it influences their teaching in ways that will best engender learners' learning for understanding.

Competence : Is static and refers to the ability to and way of using different modes of representation. This refers to external representational competence.

Fluency : Is a dynamic process referring to the navigation within and between different external representational modes.

Scientific Literacy : A scientifically literate person should be able to use clear and accurate communication skills to differentiate between vague or unsubstantiated arguments and plausible or relevant ones. Scientific literacy also points towards everyday life problem-solving skills and the ability to understand the vocabulary (science specific language) used to argue alternative views and ideas.

CAPS : The Curriculum and Assessment Policy Statement (CAPS), is the revised version of the NCS (National Curriculum Statement) of South Africa. CAPS gives teachers detailed guidelines of what to teach and assessed on a grade –by- grade and subject-by- subject basis.

Scientific Community of Practice (SCoP) – The participation in interaction with the members (some more experienced, others less experienced) of a science community where the community and the context of the community is integral to what is learned.

Mixed Methods Study: This study will be a fixed mixed method approach, meaning that the qualitative and quantitative methods are predetermined and planned according to the needs of the research questions at hand.

1.11 Summary

This study sought to investigate how pre-service science teachers use multiple representations as a pedagogical tool to explain science concepts during their lessons. The study is limited to a group of PSSTs at Stellenbosch University and selected science concepts in the CAPS curriculum. The literature argues that a good science teacher will use multiple representations to communicate and explain science concepts to their learners, and therefore there is a need to look at the use of these MRs as part of pre-service science teachers' pedagogy during their formal training. The way in which these are constructed by the PSSTs in complex classroom settings, as well as how they scaffold and translate between representations is the problem I address in this study. This is a gap that I have identified as is evident from the literature.

1.12 Thesis Outline

Chapter 2: Literature Review

In this chapter I position myself in the educational research domain. The literature study in this chapter aims to provide a foundation to underline the importance of the use of multiple representations in the science classroom and how the use thereof may potentially provide support and solutions to teaching and learning issues in the diverse South African Science classroom. I also provide a theoretical framework for the use of MRs from a social constructivist perspective where the effective use of MRs in a science classroom may contribute to more participation in a SCoP and the construction of deeper meanings.

Chapter 3: Research Methodology

This chapter sets out the research design and the methods employed to conduct this study. This chapter also presents the different stages of sampling, data collection, data analysis and the role of the researcher in the mixed methods research conducted. The chapter concludes with a discussion on the validity and reliability of the mixed method approach and how the requirements were met in this study.

Chapter 4: Results and Data Analysis

This chapter presents and organises the quantitative and qualitative results and data analyses obtained and conducted from the video recorded lesson presentations. The chapter starts with a summary of the initial coding results for each of the different groups, where noteworthy observations were pointed out and emphasised by means of descriptive statistics. Thereafter each research sub-question is addressed through four different sections.

Chapter 5: Discussion of Research Results

I begin this chapter by discussing two examples, one Physics and one Chemistry, I identified as lesson presentations which showcases relatively high levels of competence and fluency and why certain codes were assigned. The chapter continues with the very basic findings and observations made from the initial coded data for the different groups (A-F). The findings will again be aligned with previous studies' findings, where possible. This chapter will then conclude with general observations and findings of the study as a whole, indicating also the challenges that was faced during the analyses and interpretations as well as reflection on these.

Chapter 6: Concluding Remarks and Implications

In this last chapter I address each one of the research sub-questions and finally address the main research question this study aimed to investigate. I also provide recommendations for future research, especially in a South African science classroom. Lastly I will address how the results may potentially inform science teacher training endeavors and how this training may influence the PSSTs' PCK.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A considerable body of literature exists that studied the use of MRs in the science classroom. This study, however, is located within pre-service teacher education in the South African context. I have identified this as a gap in the research, especially in a South African context, and I aim to contribute to this knowledge gap through this study.

The framework of the study is constituted by a number of topics I identified and an in-depth literature review was conducted on these topics. In this chapter I also position myself in the educational research domain. The literature study in this chapter aims to provide a foundation to underline the importance of the use of multiple representations in the science classroom and how the use thereof may potentially provide support and solutions to teaching and learning issues in the diverse South African Science classroom. I also provide a theoretical framework for the use of MRs from a social constructivist perspective where the effective use of MRs in a science classroom may contribute to more participation in a SCoP and the construction of deeper meanings. The development of pre-service science teachers' use of multiple representations is seen as broadening his/her pedagogical content knowledge and fostering the creation of environments where knowledge and meaning is created through interactions with mediators, be it facilitators or MRs.

My educational philosophy, which lays out the foundation for my research perspective, and thus the way the study was conducted and results interpreted, is elaborated upon in the next section of this chapter.

2.2 Educational Philosophy

The interpretivist researcher believes that people construct their own social reality and thus the topic of research is both dependent on and formed by people themselves (Phothongsunan, 2010). This implies that people give meaning to their social environment. The nature of the relationship between the researcher and what is being studied is such that the researcher is empathetically and (inter-) subjectively immersed in the research (Phothongsunan, 2010). Phenomena can have multiple explanations and each person creates this reality in different ways across time and place (Nieuwenhuis, 2007a). In the light of this research paradigm it is also acknowledged that the social world is a very complex phenomenon and could not be reduced to just the interaction between a few factors (Phothongsunan, 2010). The researcher thus takes a nominalist position when conducting the research (Maree & Van der Westhuizen, 2007). Maree et al. (2007, p. 33) explain that this position understands that social reality can only be understood through "words and names (that are) created by the mind and within levels of individual consciousness”. However, in science education we know that even though understanding and interpretation of scientific concepts are constructed by the receiver, science teachers do not deny the existence of some scientific and real-world entities such as properties, species, universals, sets, constants, etc. Therefore I started moving from the interpretivist approach to a more constructivist approach during this study. According to Bastalich (2019) constructivism is the notion of people understanding concepts through their interaction with their environments. Bastalich (2019) elaborated on “Social Constructionism” and says it “...brings the ambivalent sense that concepts, however socially constructed, correspond to something real in the world which are reflected in our knowledge”. Gorski (2013) concluded that while interpretivists draw a line between social and natural domains, constructivists argues that the natural sciences are also linguistically constituted and are seen as a realm of social interaction. This is exactly the stance that the science education researcher wants to take in their research as to acknowledge the role of multiple representations in science teaching and meaning making of scientific concepts. Multiple representations as a “scientific language” allows for interactions that structures real world experiences. This implies that the physical world and science are viewed as not only consisting of social constructions, but are deemed as 'crucial participants' in the development of understanding scientific concepts (Crotty, 1998). I believe that even though the real world exists, it is meaningless if no attempt is made to understand it through meaning making processes by interacting with the real world and the meaning making processes of other human beings.

John-Steiner & Mahn (1996) emphasised that there is an interdependence between the social processes and the individual processes in the construction of knowledge – thus reality is created by individuals in groups. These groups can be seen as Science Communities of Practice (SCoPs) and learning in these groups is premised on social learning through participation in the practices of this community and “...the constructing of identities in relation to the community” (Goodnough, 2004, para. 3). Lincoln, Lynham and Guba (2011) elaborate on the concept of learning through CoPs as a space where individuals reconstructing their understanding and interpretations of a shared problem coalesce through social interaction to reach a consensus. Knowledge is thus constructed in a CoP through the interpretation of reality. The construction of this knowledge in a Science CoP may be attributed to the use of MRs according to Rau (2020).

Cognitive research suggests that learners need verbal sense-making competencies, nonverbal intuitive fluency as well as metarepresentational competencies to learn through means of multiple representations (Rau, 2020). In agreement with this suggestion the socio-cultural researchers posit that in CoPs learners identify with the community through both verbal and nonverbal communications, and this allows these learners to use these representations and participate in scientific disciplinary discourse (Rau, 2020). It is through combining the abovementioned suggestions that one may conclude that learners can learn through multiple representations in a science classroom where social constructivist learning theories are underlining the construction of knowledge. Social constructivist learning theories are developed from the work of Lev Vygotsky's theory on social development. I recommend this as the theoretical framework that underpins the study, i.e. social constructivism.

2.3 Theoretical Framework

The theoretical framework below introduces and describes the way people construct knowledge and paves the way for the teaching and learning of science concepts through the use multiple external representations. In turn, this describes why there is a need to look at the use of MRs by soon to be professionally qualified science teachers as part of their PCK during lesson presentations.

2.3.1 Social Constructivism

Au (1998) describes social constructivism as a meaning making process that includes active engagement and results in knowledge that may vary in nature as a consequence of being a member of a social group. Social constructivism is based on learning theories proposed by Russian psychologist Lev Vygotsky (1896-1934) who believed that cognition and higher mental functions are developed through internalisation of external social interaction (Au, 1998). Sjøberg (2007) mentions that Vygotsky's writings are integral to the concerns of educators due to his interest in understanding the conditions for human learning - socially and culturally.

John-Steiner et al (1996) mention that central to the Vygotskian sociocultural perspective lies the concept of mediation and consequently teaching and learning should rely on mediation and facilitation. When learning activities are located in social interaction the learners may to some extent develop social cohesion and in so doing integrates them in communities of practice John-Steiner et al (1996). Bozkurt (2017) states that an active process involving others is central to the acquisition of intellectual skills, while Verenikina (2010) views the construction of knowledge as an attribute of the interaction between subject (the person) and object (the natural world). Mutekwe, Machingambi, Maphosa, Ndofirepi, and Wadesango (2013) state that the social construction of knowledge points towards the importance of interaction between educators and learners where knowledge is the product co-produced amongst all parties.

The Zone of Proximal Development is a formulation proposed by Lev Vygotsky to rationalise the social impact on the level of mental functions of an individual as part of a group – this zone differentiates between what a person can mentally achieve by themselves and what can be achieved through social interaction (for instance what a learner can learn without the help of an adult vs what a learner can learn when collaborating with an adult or peer) (Au, 1998). Sjøberg (2007) acknowledges that although knowledge is personal, collaborative interaction with people, the physical world, cultural environments and linguistic environments all aid in constructing our knowledge.

Kalina & Powell (2009) see social constructivism as the realm where ideas are constructed through interaction, but that language (verbal or non-verbal) precedes thinking in the social constructivist theory. Thus the emphasis is not just on social interaction only, but on other contexts as well (Bozkurt, 2017). The power of interaction lies in the agreement of certain interpretations in a given social group or community of practice (Bozkurt, 2017). Dudley-Marling (2012) argues that these socio-cultural contexts influence how and what people learn since the context itself is part of what is being learned and mediated, and as a participant of the cultural community coordinated activity amongst members must be learned - resulting in learning that is distributed across people in a specific community of practice. It is in the Scientific Community of Practice (SCoP) that science teaching and learning is located.

2.3.2 Learning and Social Constructivism

The Zone of Proximal Development (ZPD) as proposed by Vygotsky describes the distance between independent learning and mediated or facilitated learning in collaboration with more capable others (Mutekwe, 2018). This points towards Vygotsky's emphasis on interactive learning activities as an approach to draw on diverse contexts and sociocultural backgrounds.

Churcher (2014) highlights that central to a successful learning process is the use of language between members in a CoP and as well as the use of language as part of an internal dialogue. Knowledge is thus mediated and co-created socially, followed by learning at an internal and individual level as a result of collaborative knowledge creation (Churcher, 2014) – both individual and social processes are present during the internalization of information and application for future use.

From a social constructivist perspective it is acknowledged that each and every learner brings to a learning situation their own ideas and interpretations about the world around them. Some of the learners may have had some social interactions pertaining to these phenomena and have more stable and community agreed-upon interpretations, while others might have ideas that are at odds with a specific CoP (Sjøberg, 2007). These ideas however are formulated by means of a verbal or non-verbal use of language and are the tools to understanding and interpreting the world around us, but as Sjøberg (2007) points out these ideas amongst learners are often at odds with ideas agreed upon and accepted by CoP, and more specifically in the SCoPs.

It is because of this often observed incoherence between own ideas and CoP accepted ideas that learning by means of interaction with more capable others is important in knowledge construction, especially in a specific context such as science education. Due to the diverse backgrounds of learners (think of the diversity in a South-African classroom), the ZPD for each learner may be different and the rate of internalisation may be different too, but the only way to shift a person's mental abilities to a higher level is by means of inter-mental processes with more experienced people (Verenikina, 2010). Learning in the ZPD not only encourages social and inter-mental interaction, but also awakens developmental processes internally and becomes part of the individual and independent accomplishments of a learner – also known as intra-mental interaction (ibid, 2010). Learning through a social constructivist lens thus largely refers to participation in interaction with the members of a community where the community and the context of the community is integral to what is learned (Dudley-Marling, 2012).

2.3.3 Teaching and Social Constructivism

A teacher should, when teaching from a social constructivist perspective, acknowledge that knowledge is constructed and established in groups through interaction and language (Au, 1998), but also that learners are able to perform certain tasks on their own, while other knowledge constructions can only be achieved through this social interaction with more experienced others such as teachers, peers or other members of a CoP (Mutekwe, 2018). On the other hand teachers must also realise that teaching in the ZPD does not mean that learners passively receive information from a group or more experienced others, but learning is rather an active and participatory process done by the learner (Sjøberg, 2007). The ZPD should be viewed by the teacher as the place where pedagogy and interaction coincides to produce a tool which can evaluate contributions to a learning situation (Bozkurt, 2017). However, this tool can only be used effectively if the teacher is aware of a learner's current stage of knowledge as to create meaningful learning interactions (Kalina & Powell, 2009). Bozkurt (2017) refers to research conducted in 1994 by Barbara Jaworski to point out that individual construction of meaning (internalisation) in a social dimension manifested through the use of verbal and non-verbal forms of communication. She also found that in learning situations teachers are pivotal in contributing to learners' learning by using and providing both language (every-day language and context specific language) and participation as part of their pedagogy. Verenikina (2010) says it is not just the intervention of a teacher in a learner's learning that is imperative, but also the quality of the teacher-learner interaction. Dudley-Marling (2012, p. 3) paints this idea as follows:

> "The teaching-learning interaction can be likened to an intricate dance to which both students and teachers contribute. This dance is mediated by the curriculum, school policies, the culture of the school and classroom (and schooling more generally), the language of students and

> teachers, and so on. The meaning of coordinated actions – in this case school learning – also relies on just the right people doing just the right moves in a particular time and place. Returning to the dance metaphor, learning the dance depends on people working together to accomplish a particular set of moves that will be recognized as dancing. These moves cannot be accomplished by a person acting on their own or without the aid of music and, perhaps, props (certain dances requires specific clothing, spaces, etc.)."

Olaleye (2012) investigated how using MRs as part of teacher pedagogy while teaching science enhanced the participation and quality of the teacher and learner interactions, and found that when teachers use various representations to explain abstract science concepts, learners found these to be more accessible and relatable. This is expanded upon next.

2.3.4 Multiple Representations in Social Constructivist Teaching and Learning of Science

Rau (2020) proposed two reasons for the use of multiple representations and argues that these two reasons are determined by two different theoretical research focuses namely cognitive and socio-cultural research. Cognitive researchers may focus more on the use of MRs for learning on an individual level, indicating a more pedagogical implication, while socio-cultural researchers place the emphasis on a community level and this points towards a more professional implication (ibid.). The author states that learning through MRs on either an individual or community level can take place based on the notion that:

- Different representations may complement one another because of their similarities and differences.
- They may also drive one another if one representation leads to the understanding of another one.
- Lastly, when different representations of a specific concept are used it may lead to the development of a deeper meaning and insight.

In support of the use of learning through MRs, research distinguishes between symbolic and visual representations and also argues that even though both modes are processed in the working memory, they are processed in different parts of a person's working memory – thus having both a symbolic and visual representation of a concept engages two parts of the working memory and this may lead to an increased working memory capacity and more effective learning (ibid.).

However, using MRs to teach or learn about a concept may potentially obstruct learning if one does not understand how information is presented in a representation or if one cannot integrate and translate information across multiple representations (Rau, 2020). In other words, if there is no competence or fluency when teaching and learning with MR's the use of these MRs may in fact cause more damage than promote the construction of knowledge. Rau (2020) refers to this problem as the *representation dilemma*. Cognitive research and socio-cultural research address this representation dilemma on two different ways. Cognitive research argues that a learner (and therefore a teacher) must possess representational and connectional sense-making competencies, demonstrate representational and connectional fluency, and show meta-representational competence when selecting appropriate representations and critiquing or modifying representations (ibid.). On the other hand, socio-cultural research does not see the representational dilemma as a problem, but rather as part of the process of becoming part of and integrating into a community of practice through means of verbal and non-verbal communications as well as reflecting on community practice (Rau, 2020). It is in the socio-cultural stance that we find the link between the use of MRs for teaching and learning and the mediating aspect of a social constructivist approach to teaching and learning.

According to Mutekwe (2018) Lev Vygotsky viewed a mediator not only as human (peer, parent or teacher for instance), but acknowledged that a mediator could also be the tool(s) used in a teaching and learning process to enhance a learner's understanding of a concept under discussion. Vygotsky lists a few mediators such as other human beings, materials, psychological tools as well as semiotic tools to transcend cognitive functions to higher levels (Mutekwe, 2018).

Mutekwe (2018) refers to Tudge's (1992) research that lead to the assertion that all teaching aids used to enhance learners' cognitive functions may be seen as learning tools. Examples of teaching aids mentioned by classroom practitioner participants during Tudge's research includes gestures and semiotics – part of the learning tools Vygotsky termed as psychological tools (Mutekwe, 2018). Kozulin (1998, "Abstract") identifies these psychological tools as "symbolic cultural artifacts - signs, symbols, texts, formulae, and most fundamentally, language - that enable us to master psychological functions like memory, perception, and attention in ways appropriate to our cultures". These cultures may be interpreted as CoPs. This implies that in a specific context the use of these learning tools can shift a learner's knowledge foundation to a higher level – and that is the ultimate purpose of effective and efficient teaching and learning (Mutekwe, 2018). Mutekwe (2018) found that not only does mediated learning lead to a shift in a learner's ZPD, but it also assists in the fostering of equitable learning in the classroom, an aspect of learning that is very relevant to the South African context.

In Vygotsky's theory he differentiates between every day concepts and scientific concepts – every day concepts are viewed as knowledge gained through daily living while scientific concepts are learned through formal instruction and interaction with members of SCoPs (Au, 1998) and Vygotsky brings together these two types of concepts in the process of development, where both concepts add to the development of the other.

According to Bozkurt (2017, p. 213) an integral part of co-construction of knowledge is the use of semiotic mediation and internalisation of these semiotics plays a pivotal role in the "autonomous problem solving processes as well as the progress of knowledge co-construction". In SCoPs the significance of semiotic mediation in language, thinking and processes of internalisation is widely accepted (Bozkurt, 2017). Vygotsky (1981, p. 137) defined semiotic as: "language; various systems of counting; mnemonic techniques; algebraic symbol systems; works of art; writing; schemes, diagrams, maps and mechanical drawings; all sorts of conventional signs and so on". Lev Vygotsky is therefore the one that introduces us to the idea of learning through external and mediated activities and the idea that internal cognitive processes can only be known if the tools that mediate those processes are understood (Verenikina, 2010). Rau (2020, p. 27) summarised this idea as follows:

> "...social practices of using representations for nonverbal communication involve becoming fluent in a multimodal language that allows students to seamlessly infer what information individual representations show about community-specific phenomena and to flexibly translate among multiple representations. The practice through which students acquire fluency in this multimodal language... they describe (as) group-level perceptual fluency in communication."

It is thus of immense importance that teachers and learners be integrated into these communities, starting in the science classroom, to such an extent that the members of this community can communicate in a multimodal language to interpret and convey meaning.

2.3.5 Social Constructivism and Multiple Representations in a South African Science Classroom

The perspective of teaching from a social constructivist point of view addresses the learning issues often experienced by learners form diverse backgrounds (as in the case of South African classrooms) in terms of school context literacy (Au, 1998). Diverse backgrounds in the South African context refers to linguistic, cultural, religious and socio-economic diversity. According to Kalina and Powell (2009) social interaction is necessary in order for people to embrace diversity, and in order for us to embrace diversity effective communication is key. Unfortunately in order for communication to take place as effective as possible all parties must to some extent share a common ground, and thus one can say that constructivist teaching practices are vital to reform efforts in education since using language (in all forms) is the most dominant process in a social constructivist learning situation (Kalina & Powell, 2009). Social interaction and language usage is thus entwined and dependent on one another for growth in either one – and it is through the combination of these two that we can establish effective communication and equitable learning in the South African classroom in order for us to start to embrace diversity. Cooper and Stowe (2018) say that in order for learning to take place in a group or social setting and for it to be more beneficial to all participants, the group must be as heterogeneous as possible, and as this means that no member is isolated during learning.

In a recent (2018) South African study it was found that one of the most crucial components for establishing a learning community in a diverse classroom is to use every day experiences of learners in social activities to serve as motivation for participation (Mutekwe, 2018) – these everyday experiences can be seen as markers of common grounds shared. However, a study discussed by Bozkurt (2017) found social interaction not to be helpful in learning when ineffective communication takes place. This then points towards classroom practices where social interaction takes place, where measures of effective communication are set in place and where mediation by a more experienced other takes place.

One of these measures of effective communication in specifically SCoPs may be the use of multiple representations to effectively communicate (explain and understand) specific scientific concepts. Dudley-Marling (2012, p. 2) proclaims:

> "Conventionally, learning is understood to be a matter of acquiring knowledge and skills. Children learn to talk, read, and write, for example, by acquiring a set of skills associated with effective reading, writing, and speaking. However, a social construction of learning holds that people don't learn to read, write, or speak "once and for all." Instead, they learn to read, write, and speak in particular ways, for particular purposes and audiences, in particular social settings. Specifically, reading, writing, and speaking are sets of social practices that enable participation in particular cultural activities in various cultural communities. Crucially, these social practices involve more than mastering a set of linguistic skills (vocabulary, syntax, etc.). Language practices, for example, always involve ways of behaving, thinking, interacting, valuing, believing, and speaking, in short becoming particular kinds of people."

In other words, using language effectively during social interaction in specific contexts to mediate meaning involves being a specific person – a member of that CoP. To successfully be part of a community of knowledge one needs to know how to communicate effectively to other members by means of constructing an identity that resonates with this specific CoP. In a scientific context one needs to know various ways of communicating scientifically and effectively and must thus use science specific communication aids – multiple ways of representing ideas – but in order for us to learn how to use these science specific communication aids we need to effectively interact with other members in the science community. Thus the collaborative performance is necessary in order for an individual to establish independent performance to use at a later stage (Verenikina, 2010).

One would be ignorant to say that the social constructivist perspective of learning leads to successful learning only, as it is also the collaborative efforts of systems, schools, teachers, peers, communities and families that may lead to failure in literacy and contextual learning, since we belong to various communities simultaneously which might not share a common perspective on phenomenon. This then just reiterates the importance of a community specific identity and brings the focus back to interaction through a multimodal language.

I thus approached the study from a point of view underpinned by a social constructivist perspective, since research conducted from such a perspective aims to address ways in which school teaching and learning activities, and as such teacher training and PCK development, can be reformed or restructured. This has to be done as to empower teachers and learners from diverse backgrounds to acquire and co-construct academic knowledge (science concepts), become part of a science community of practice and communicate effectively as a member of such a community - all while drawing from and building on their personal background and experiences (every day concepts). For science teachers this would imply that they acknowledge the different ways in which we learn, draw on various ways of representing science concepts and making links as to engender knowledge construction and know what it takes to become integrated into and develop an identity that associates itself with a SCoP.

2.4 Pedagogical Content Knowledge (PCK) in Science Education

According to Cochran (1997) teachers have a unique type of knowledge and this knowledge is a combination between their pedagogical knowledge and their content knowledge. This special type of knowledge can be explained as an integrated version of how they teach and their knowledge about what they are teaching. It also includes the knowledge of what a student could experience in terms of level of difficulty and possible misconceptions (Shulman, 1986).

Shulman (1987, p. 8) highlighted PCK is knowledge that distinguishes a teacher from a content specialist, a ‘special amalgam’ of content and pedagogy. This includes understanding how a learning domain is organised, and how it can be adapted to learners’ interests and abilities and presented for instruction.

Magnusson, Krajcik, and Borko (1999) defined PCK as the result of a transformation of knowledge from other domains and emphasised its role in the planning and conducting of, and reflecting on teaching. Gess-Newsome (1999a) identified two fundamentally different conceptualisations in the work on PCK. The first corresponds to Shulman's original transformative perspective, in which other knowledge bases combine to form new, distinct knowledge. The second adopts an integrated perspective, in which PCK is knowledge generated when teachers draw on other knowledge bases and connect knowledge from these knowledge bases in new ways. Hashweh (2005) leans towards an integrative perspective on PCK that implies teachers draw on knowledge bases in constructing PCK for classroom use. While Loughran, Berry, and Mulhall (2012) include similar components to Hashweh (2005), they also describe PCK as an 'amalgam' of knowledge developed through experience which implies PCK is transformative.

Nilsson (2008) and Loughran, Mulhall, and Berry (2008) respectively investigated the articulation and development of student teachers' PCK during pre-service education at elementary and secondary levels. Nilsson (2008, p. 1295) noted student teachers' reflections on having "their knowledge bases as a transformed unit", concluding that moving from individual knowledge bases to the complex interaction between them was crucial for improving teachers' practice. Loughran et al. (2008) introduced pre-service teachers to PCK through novel data collection methods, namely, 'Content Representations' (CoRes) and 'Pedagogical and Professional-experience Repertoires' (PaP-eRs). They observed that participants attempted to align subject matter content with pedagogy such that content would be better understood by learners (p. 1317). Both papers implement a transformative perspective in which PCK is an amalgam of content knowledge (CK) and pedagogical knowledge (PK) (Gess-Newsome, 1999b). In the study conducted by Kurnaz & Arslan (2014) it was found that where the use of MRs to teach the concept of energy was part of the teachers' PCK, it contributed to more meaningful teaching and learning during the teaching process. Thus, the use of MRs not just only enhances the learners' experience of the science concept, but also improves and transforms the teachers' PCK.

Science teachers with a strong PCK should be able to deliver content through various methods and representations, and in so doing it potentially places the teachers in a position to embrace multiple representations not only in their Content Knowledge but also in their Pedagogical Knowledge. A strong PCK would allow teachers to foster learning about concepts and the ways we represent them, in order to avoid the representational dilemma where "students use representations they do not know to learn concepts they do not know" (Rau, 2020, p. 29).

2.5 Multiple Representations in Science Education

Gilbert and Treagust (2009a) used the term "representation" for external, visible representations as well as for internal representations, while most research about multiple representations (MRs) use external representations such as visualisations. However, for Ainsworth (1999, 2006), learning with multiple representations means that two or more external representations are used simultaneously. In addition to classical formats of multiple representations such as written text or instructional pictures, mathematical models may be included in physical sciences and natural sciences education. According to Lesh and Doerr (2003) the understanding of a concept cannot be thought of as an all or nothing approach, but rather the development of ideas. It should be noted, however, that just combining words, pictures, mathematical expressions or other kinds of visualizations does not automatically guarantee meaningful learning (Opfermann, Schmeck & Fischer, 2017). The authors conclude that the use of multiple representations can foster learning as they address different areas of the working memory and support the construction of coherent and integrated mental models.

> " …learning with multiple representations takes place when any two or more external representations are used in instructional materials. In a classical multimedia view, this can comprise (written or spoken) text and accompanying pictures, but multiple external representations (MERs) can also include photos, diagrams, tables, graphs, concept maps, or even notes taken during learning" (Opfermann et al., 2017, p. 8)

Chamberlain and Crane (2008) similarly stated that through the use of multiple representations teachers can relate content to a variety of learning styles such as visual, auditory or kinaesthetic learning. A variety of representations may also bridge the discrepancies of the one size fits all approach in science classrooms, and more specifically in South Africa, by addressing and linking to multiple intelligences as set out by Howard Gardner (Manner, 2001). Learners must be able to evaluate and challenge and adapt information as well as their understanding of a concept by comparing a variety of informative sources (MRs). In the examples discussed below, it is evident that different concepts can best be described by select representational modes, and often teachers and learners must use a combination of the most appropriate representations to convey meaning successfully.

Kuo, Won, Zadnik, Siddiqui & Treagust (2017, p. 124) mentions that MRs are specific to their scientific and educational purpose but can generally be classified as:

a) descriptive: this includes words, graphs and tables

b) figurative: which allows for pictures, analogies and metaphors to be used

c) Mathematical: such as formulae etc.

d) experimental experiences or demonstrations

e) kinaesthetic or embodied representations

The authors conclude that learning with MRs is a powerful way to facilitate understanding in science education. In other words, using MRs helps teachers and learners to make a variety of symbolic descriptions about meaningful situations or concepts (Lesh & Doerr, 2003). The authors say that the ultimate goal of using MRs is to allow an individual to construct and deconstruct meaning as if they were a group of people working together around a table negotiating a stable version of knowledge (Lesh & Doer, 2003). The selection of the most appropriate representational modes can be guided by various factors, but the requirements of the concept itself is most important and these requirements may differ on the basis that it is classified either as a physics or chemistry concept.

2.5.1 MULTIPLE REPRESENTATIONS IN PHYSICS

Time in seconds	Velocity Car 1	Velocity Car 2
0	0	0
1	4	1
2	8	4
3	12	5
4	16	7

$$a\,(t) = \frac{\Delta v}{\Delta t}$$

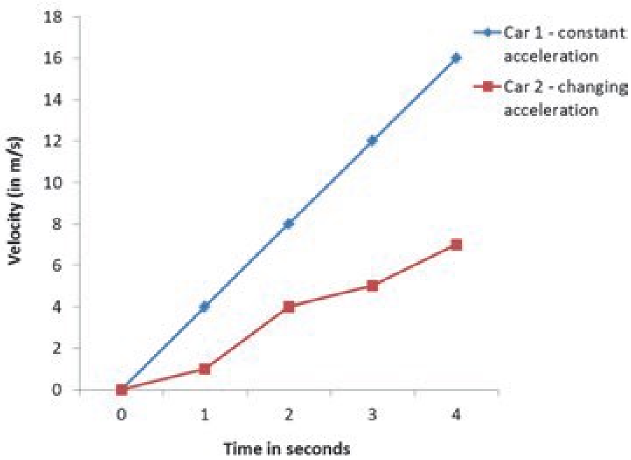


Figure 2.1: The table, mathematical equation and the graph convey complementary information

In Figure 2.1, these MRs could complement what the physics teacher is explaining about acceleration when doing rectilinear motion as a topic, and Lesh and Doer (2003) refers to this as embodiment of the explained concept. It also affords different learners an opportunity to learn in a way that suits them when confronted with the concept of acceleration. These MRs can also promote deeper understanding as conveying the concept by means of one representation can potentially limit understanding, but it also makes it possible for the student to be able to translate between different representations (Ainsworth, 2006). Lesh and Doerr (2003) agree and mention that different modes of representation will emphasise and de-emphasise different aspects of the concept it is intended to explain or describe, and that meanings tend to be distributed over a variety of representations that leads to a more realistic understanding. Opfermann, Schmeck and Fischer (2017, p. 18) conclude that "using MRs is a necessary prerequisite for students' own construction and reconstruction of meaning not only from instructional materials provided but also to understand the internal structure of physics concepts expressed in different forms of representations".

Kind, Angell, and Guttersrud (2017) have argued that learners typically see physics and mathematics as separate modes of thinking and therefore have problems seeing the physics when the mathematics is manipulated. An example that comes to mind is that current is inversely proportional to resistance (I=V/R) which simply means that as the resistance increases the current would decrease proportionally. This should be intuitive without having to manipulate the equation. The authors also use a socio-cultural argument that shifts the focus of learning as something that occurs exclusively inside someone's head to one where knowledge and reasoning are socially constructed. Their study was aimed at developing teaching material and methods to improve physics teaching and make students better at using and making interchange between representations in physics. They concluded that teachers need more support to operationalise the intended learning outcomes in their teaching of physics.

In physics there are a few commonly used modes of external representation, which includes formulae, graphs, tables, diagrams, sketches, figures, mathematics, practical demonstrations and specialist language (Airy & Linder, 2017). According to these authors a wide array of representations can potentially create disciplinary meaning. They also refer to "critical constellations of semiotic resources" which they define as the use of MRs that is "necessary for an appropriate experience of disciplinary knowledge". This idea is clarified by the authors when given the following explanation (Figure 2.2):

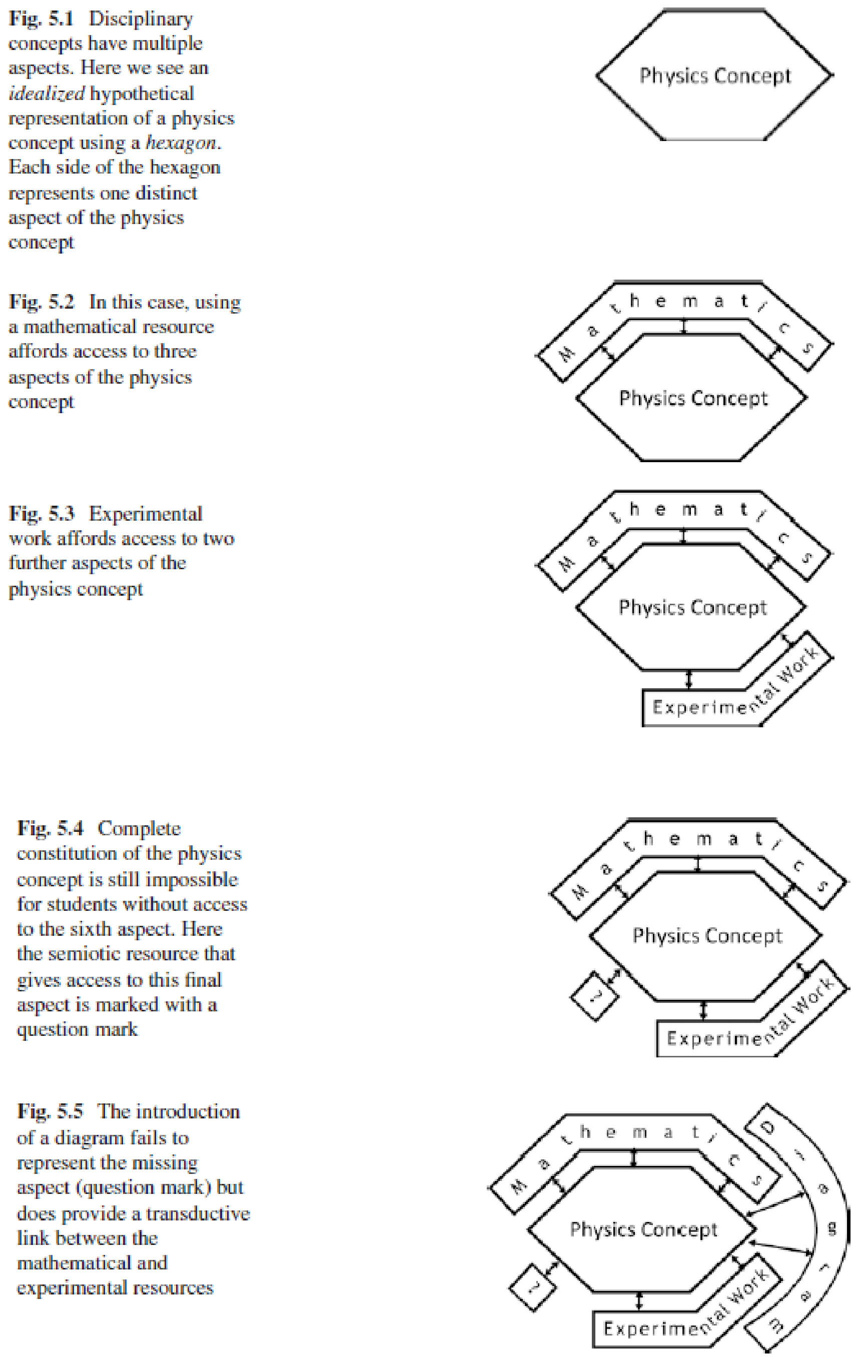


Figure 2.2: Critical constellations of semiotic resources showing that MRs can contribute to a more complete understanding of a physics concept (Airey & Linder, 2017, p. 100)

Potentially the missing aspect referred to in this constellation may be the use of written or spoken words.

2.5.2 MULTIPLE REPRESENTATIONS IN CHEMISTRY

In chemistry, there are three types of representations Gilbert & Treagust (2009b) identify to express chemical ideas:

a) The first type of representation seeks to represent phenomena as experienced with the senses (or sense-extensions) called the phenomenological type. Examples are properties such as mass, density, concentration, pH, temperature and osmotic pressure.

b) The second seeks to support a qualitative explanation of those phenomena called the model type. Models are used for causal explanations of phenomena such as solids, which can be described in terms of packed atoms or molecules.

c) The third seeks to support a quantitative explanation of those phenomena called the symbolic type. This level involves the allocation of symbols to represent atoms, whether of one element or of linked groups of several elements.

Learners also encounter a range of symbolic representations in chemistry according to Taber (2009):

- To symbolise element names (H, He, etc.)
- for atomic number and mass (A and Z);
- for various measurable quantities (n, m, V, P, etc.);
- for the units of such measurement (mol, kg, m^3, Pa, etc.);
- for mathematical relations such as ΔH;
- to indicate oxidation states in systematic compound names, e.g. iron (II) chloride.

Using a constructivist perspective, Taber (2009) argues that "a learner's existing knowledge and understanding provides the interpretive framework used to 'make sense' of a teacher's presentation" (p. 79). He cautions, however, that these symbolic representations may act as learning impediments when a learner distorts the intended meaning and just reiterates the fact that science teacher training should be conducted in such a way as to avoid the representation dilemma.

1 $2Mg + O_2 \rightarrow 2MgO$

2 $2NaOH_{(aq)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)}$

3 $CaCO_3{}^{\Delta} \rightarrow CaO + CO_2 \uparrow$ [Δ should be above →]

4 $AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow AgCl_{(s)} \downarrow + NaNO_{3(aq)}$

Figure 2.3: Typical chemical equations

Representations such as in Figure 2.3 could be considered a fundamental part of the language for communicating chemistry. Taber (2009) also states that there are several levels of skill needed for full competency in the language of chemical equations, and their absence could lead to mistakes. He suggests that the teacher must use a scaffolded approach with consolidation at each level.

From the literature it is evident that previous studies have attempted to measure representational competence of student teachers; these were all context specific in chemical education, biological education, etc. (Kozma & Russell, 2005; Halverson & Friedrichsen, 2013; Mishra et al., 2018). One of the key skills a science teacher should develop as part of their PCK is the mastering of and selection of appropriate modes of representation needed for a specific purpose and with a specific goal in mind (Prain & Tyler, 2013) while the context provides the setting against which this selection must take place. Science teachers should thus be competent in the representational modes required to teach a science concept. However, Daniel et al. (2018, p. 4) argues that in order for us to investigate pre-service teachers' representational competence, representational fluency too must be addressed.

2.5.3 REPRESENTATIONAL COMPETENCE AND FLUENCY

Representational competence is static and refers to the ability to and way of using different modes of representation, while representational fluency is a dynamic process referring to the navigation within and between different representational modes (Daniel et al., 2018). Lesh and Doer (2003) refers to representational fluency as going beyond simply using different representations to the ability to understand and explain why different modes can be used to explain a specific concept (or specific aspects thereof). Rau (2020) argues that representational fluency can be interpreted in two different ways depending on which research perspective is used. When conducting research from a cognitive perspective representational fluency is based on the liaison between the internal and external representations a person has, while from a socio-cultural perspective representational fluency would refer to the selection of and translation between various representations to convey deeper meaning to a concept (Rau, 2020). From a social constructivist perspective the latter is accepted as representational fluency, and the former as part of representational competence. Four representational modes, as identified by Maree and Edwards (2019), are illustrated in Figure 2.4 below:

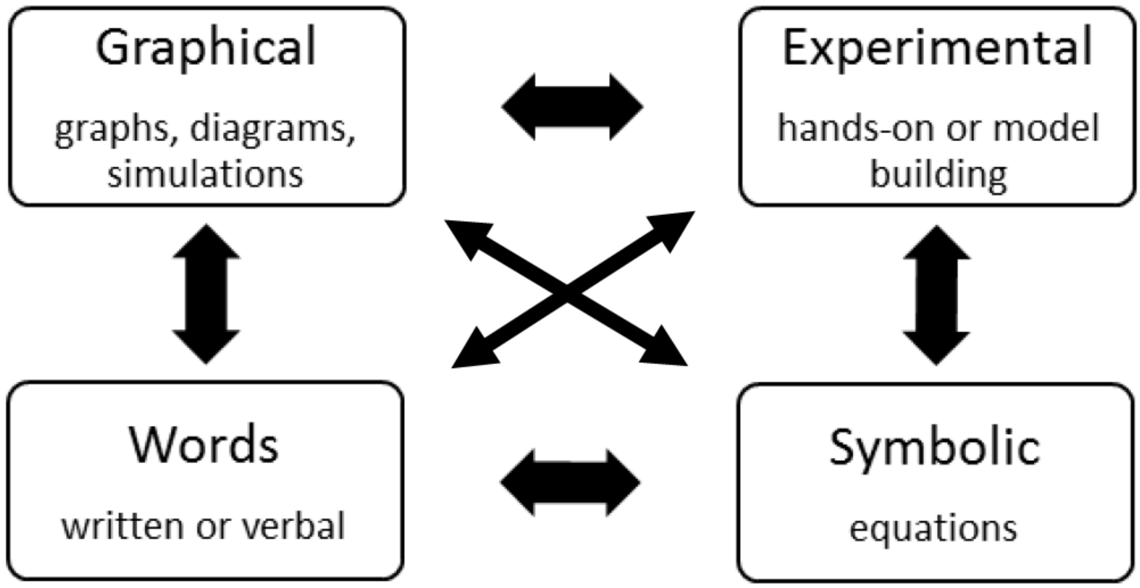


Figure 2.4: A representation model by Maree and Edwards (2019) indicating categories of competence and fluency (adapted from Lesh & Doerr, 2003)

This model is based on an overall approach for physics and chemistry concepts combined. In this model competence would be indicated by using a specific representational mode correctly and showing how that specific representation convey information about a specific concept. Representational fluency is indicated by the interactions (arrows) between the representational modes. However, a problem that arises from the model in Figure 2.4 is the issue of distinguishing between everyday words that makes out part of a person's everyday language (non-specialist) and the words specifically used in science or words with a contextual meaning in science (expert) as proposed by Lesh and Doerr (2003). The authors explain this by saying that non-specialist use of words is usually unpretentious and productive, whereas the expert use of words is to know more and to know different (Lesh & Doer, 2003), while the linking between the two is necessary for the meaning-making process (Larsson & Jakobsson, 2019). One pivotal aspect of successful comparison and connection of various informative sources is the effective use of language. It is therefore important to look at use of language in science and scientific literacy as a representational mode and how it contributes to teaching and learning of the subject, which will be elaborated on in Section 2.6. Since this study is guided by a social constructivist perspective the successful use of MRs by teachers and learners in a collaborative environment lies embedded in the ZPD as proposed by Vygotsky. Without the mediation by teachers and various representations of a science concept, learners may not be able to shift their ZPD to a higher cognitive level regarding these concepts specific to a CoP. However, the use of these MRs must be effective and of high quality, otherwise teachers might contribute to the failed attempts of creating knowledge and learning in the younger members of the SCoP. In the next section I elaborate on the importance of language in teaching and learning science.

2.6 Language in Science and Scientific Literacy

Language plays an integral role in learning science, whether it is written or verbal use of words. A few examples may include instructions for an investigation, explanations for a scientific phenomenon, report writing, researching information on a topic as well as teacher and learner interactions (Short, Short, Vogt, & Echevarría, 2011). Larsson and Jakobsson (2019) argues that Science teaching and learning should strengthen the learners' abilities to use relevant language in a variety of situations for various purposes. Their study concluded that there should be an awareness of different language usage within science and a SCoP to enhance the meaning-making process (Larsson & Jakobsson, 2019), and that this conclusion is especially significant when referring to multilingual learners. According to Prinsloo, Rogers and Harvey (2018, p. 1) the contribution of language factors to poor science achievement in South Africa were strongly associated with how often learners used "school language" at home. In this case school language was defined as the language of learning and teaching in the classroom. The argument continues that academic achievement in the subject of science is dependent on sound language proficiency in first and additional languages, due to the extent to which learner achievement in a language-based subject could be negatively impacted by a lack of foundational skills (Prinsloo et al., 2018). Howie, Venter and Van Staden (2008) attributed literacy issues in South African school learners to the mismatch between the multilingualism policy and the practicality of the implementation of this policy. In South African schools (mainly due to Westernised approaches to education) there is a general perception that English proficiency is necessary for success and even though the English language is indispensable for international scientific communication, this poses challenges for second and third language learners.

In the study conducted by Prinsloo et al. (2018) it was found that the greatest impact on science scores in South African classrooms was the equivalence of home language and school language, followed by the frequency of speaking the school language at home. South Africa has 11 official languages, but teaching and learning mostly takes place in English, even though only 8,1% of South Africans used English as their first language in 2019 (South African Government, 2019). Every day there are learners sitting in South African science classrooms expected to engage with topics that are completely unfamiliar to them, and even if the topic was familiar to them (they may even have an array of skills and understandings around the concept) they may struggle to fully comprehend the concepts because of the language barrier. These issues may stem from the school language vs home language barrier, or it may stem from the content- and context-specific language barrier (Short et al., 2011). Part of my argument in this study is to emphasize the importance of the use or MRs by science teachers in South Africa as to try and overcome certain struggles in the classroom due to language issues – representing concepts in ways where words may fail. This does not mean that we will be able to do Science without the use of words, but if we only use words (written or spoken) science education in South Africa is sure to continue to fail the broader society. In the Exploratorium release on Developing Language in the Context of Science (Institute for Inquiry, 2015) engaging in inquiry-based science can provide context for language development just as well as using language to communicate ideas and understanding can develop scientific understanding.

According to Chamberlain and Crane (2008) a scientifically literate person should be able to use clear and accurate communication skills to differentiate between vague or unsubstantiated arguments and plausible or relevant ones. Scientific literacy also points towards everyday life problem-solving skills and the ability to understand the vocabulary (science specific language) used to argue alternative views and ideas (Chamberlain et al., 2008). This supports the notion of empowerment of learners in terms of language, since teaching and learning science is a social as well as a personal exploration that should lead to conceptual change (Chamberlain et al., 2008). Lesh and Doerr (2003) agree that scientific literacy includes inquiry and self-discovery, and this links to the idea of differentiating between non-specialist words and the expert words specifically used in science. Each and every person has a collection of prior knowledge systems and is what Pierre Bourdieu (1973) refers to as a person's cultural capital, none of them static but rather dynamic. In the case of science learners their informal ideas (that may be unstable) about science concepts can be restructured to ideas and knowledge that are more consistent within the science community (more stable). Teaching and learning science based on this notion means that learners will need to engage with science process skills to perform investigations facilitated by teachers as to "know differently" through the encounter (Chamberlain et al., 2008). It is in this case that the learners and the teachers become partners in science teaching and learning, where the learners are also playing a role in producing knowledge and not only act as receivers of knowledge as is often the case. In this study the focus is not on the process skills, but rather the different ways in which we can represent specific science concepts and how this helps learners to engage with and align their understanding of these concepts – one of the ways being the use of words. The findings of Larsson and Jakobsson (2019) highlights the fact that school science should be seen as a language activity and that both teachers and learners should be aware of disciplinary (content-specific) literacy in relation to everyday literacy. Due to this reasoning, it is of importance for us to determine whether scientific literacy is apparent in this study and whether pre-service teachers distinguish between everyday (non-specialist) words and science-specific (expert) words (Lesh et al., 2003). To allow for the distinction to be made between the two ways of using words as a representation of a science concept, the model in Figure 2.4 was adapted to include expert words and non-specialist words as set out in Chapter 3 (Figure 3.1).

In the Competence and Fluency of MRs Model in Figure 3.1 (see Chapter 3) a distinction is made between non-specialist (general) words and expert (content-specific) words, and when the two classifications are combined we may classify it as academic language. Short et al. (2011) suggests in *The Academic Language of Science* that one can think of content-specific and general language in science as bricks and mortar – we cannot only use everyday language to engage with science as unintended meanings may arise, but just as well we cannot use sophisticated terminology only as it may result in jargon that excludes some or most people from understanding scientific concepts (Lesh & Doerr). Academic language, according to Short et al. (2011), is essential for academic success in schools, and is more challenging than conversational language – even more so for second language learners. Thus, for learners to develop sound language skills in science they need multiple opportunities to engage with academic language, both general and content-specific as to "negotiate meaning through confirming and disconfirming their understanding while they work and interact…" (Short et al., 2011, p. 14). Larsson and Jakobsson (2019) refers to this as a hybrid of languages or the inter-language nature of academic learning environments, and informally refers to it as "double-talking". Even though this study does not focus on the learners, but rather the pre-service teachers, one can argue that the teacher must master the ability to use academic language in all its forms as to facilitate a classroom setting where academic language plays a role in the academic success of the learners and one where the learners are the ones practicing academic language, not just the teacher.

From the model in Figure 3.1 it is evident that science teachers should be competent in five different modes of representation namely Graphical, Experimental, Symbolic, Non-specialist Words as well as the use of Expert Words. The connections between the different modes in Figure 3.1 implies fluency – translating from one to the other. Lesh and Doerr (2003) argues that it is important that accurate translation between different modes take place otherwise inconsistencies in thinking and understanding may go unnoticed when using different representations. The layout of this model emphasise the idea that there are interactions between all of the different modes of representation (competence and fluency), but that all of these modes lie within and are embedded in the context of the Words used. The use of Expert Words was placed at the centre of the model as to imply that all of the other modes come together at the focal point of scientific literacy and the use of content-specific words that are used in a science context – this is the effective and specialised language to be used in a SCoP. The use of Non-specialist Words, or everyday language, was placed on the outside surrounding the other modes of representation as to suggest that the use of everyday literacy is embedded into each one of the other representations and that one won't be able to interpret or explain any of those without a sense of everyday language. Placing the use of Words, Expert and Non-specialist, at the centre and the circumference of the model respectively, points towards the immense importance of language and literacy in this science community setting where teaching and learning of science concepts occur.

According to literature the following aspects enables one to distinguish between the two classifications of words in science teaching and learning as either everyday language or expert use of language (context specific):

Table 2.1: Description of non-specialist use of language in Science vs expert use of language in Science

Non-specialist words in Science	**Expert words in Science**
General academic words like identify, risk, region, increase, etc. that one could encounter in other subjects or everyday language as well (Short et al., 2011)	General academic words like table, mass, wave, property, etc. that one could encounter in other subjects or everyday language as well, but has a science specific meaning that is perhaps different to the everyday meaning (Short et al., 2011). Words such as work, energy and power are good examples.
General academic language, like the use of terms such as demonstrate, analyse, category (Baily & Butler, 2007)	Content-specific academic language, like the use of terms such as density, hypothesis, inertia (Baily & Butler, 2007)
Comprehension of a language	Terminology, concepts, phrases, names, etc. that are completely unique to Science.
Concrete, simple, general, intuitive, decontextualised, internal, crude, unstable (Lesh & Doerr, 2003)	Abstract, complex, particular, formal, situated, external, refined, stable (Lesh & Doerr, 2003)
SIOP Model: Words and word parts that teaches language (school language) structure (Echevarria, Vogt & Short, 2008, p. 59)	SIOP Model: Content words and Process/Function Words (Echevarria, Vogt & Short, 2008, p. 59)
Language intensive (Lee, 2013)	Academically rigorous (Lee, 2013)
Using their "real heads" (Lesh & Doerr, 2003) for engagement with school activities	Using their "school heads"(Lesh & Doerr, 2003) to close the gap between school, academics and real life
Productive language that allows ordinary people to think and explain (Lesh & Doerr, 2003)	

Looking at the different descriptions in the literature it corresponds to what Churcher (2014) highlights that central to a successful learning process is the use of language between members in a CoP, and in this case being part of a science community of practice would require learners to use language (in all its forms such as verbal and non-verbal) which is context specific and as used by more experienced member of this SCoP.

2.7 Summary

The literature study in this chapter provides an argument and a solid foundation for a study underpinned by a social constructivist perspective on how the use of multiple representations in the science classroom may potentially provide support. It may even provide a solution to the science education conundrum in South Africa, especially in terms of language and literacy, and why pre-service teachers should be able to include MRs as part of their PCK. This literature review also establishes a sound argument of the importance of teacher training in terms of representational competence and fluency, as well as the selection of appropriate representational modes relevant to achieve a specific goal in science education. This study also encourages the science teacher or facilitator to reflect on their teaching methods as well as their PCK. Verenikina (2010) argues it is not just the intervention of a teacher in a learner's learning that is imperative, but also the quality of the teacher-learner interaction and thus it is the responsibility of the teacher (the more experienced other, the mediator and the facilitator) to structure learning situations as to encourage quality interactions and effective communications. It is in the light of this that I conduct this study as to potentially gather some insight about pre-service science teachers use of MRs during practice teaching sessions and their structuring of these learning situations they create for learners.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This study was designed to explore and investigate the use of multiple representations by pre-service science teachers during lesson presentations. This chapter sets out the research design and the methods employed to conduct this study. This chapter also presents the different stages of sampling, data collection, data analysis and the role of the researcher in the mixed methods research conducted. The chapter concludes with a discussion on the validity and reliability of the mixed method approach and how the requirements were met in this study. I chose a mixed method approach due to my belief that the use of MRs in science teaching is a very broad field of study and I wanted to narrow it down to a more focused and researchable topic with a very specific setting. I believe a mixed methods study will enable me to get a more comprehensive view of this focused and narrowed down topic.

This study is underpinned by a social constructivist perspective. The aim of the study is to inquire about a phenomenon (the use of MR by pre service science teachers) and the setting of the inquiry is within its real-world context (Nieuwenhuis, 2007b). This setting can be described as a classroom, where the pre-service science teacher may (briefly) know or may not know the learners in front of them. These classrooms will be located at either Stellenbosch University or at schools in close proximity to this university. The research design of this study is discussed in the next section of this chapter.

3.2 Research Design

Below is set out the research methodology and methodological considerations which comprise this study's research design.

3.2.1 Research Methodology

Kothari (2004) described research methodology as a way to solve the research problem step by step. Research methodology may be viewed as the science of conducting research where the researcher not only looks at systematically conducting research, but also the dialectics behind each step of the way (Kothari, 2004). Thus, the research methodology refers to the methods used to conduct the research as well as the reasons behind using specific methods, how these methods fit into the context of the study and the educational philosophy of the researcher, as well as the nature of the research problem in question. Cohen, Manion & Morrison (2013, p. 47) refers to the aim of the research methodology as "to help us to understand, in the broadest possible terms, not the products of scientific inquiry but the process itself".

Social sciences research predominantly sits in either a positivist or a constructivist approach (Patel, 2015). A positivist approach would want to study reality as if there is a single truth and when applied to social psychology it views reality and people's interpretation thereof as a set of facts that can be measured quantitatively; A constructivist approach deems reality as a collection of interpretations and when applied to social psychology, in this case social constructivism, reality is viewed as the social consensus of the real world between people in communities and thus requires a more qualitative approach (Patel, 2015). Denzin and Lincoln (2005) concluded that it is the subject under investigation and the nature of the research question that determines the research methodology. The perspective of the researcher on social sciences, and more specifically educational research, must provide the lens through which all of the research process should be viewed. As discussed in the theoretical framework of this study I approached the study from a social constructivist perspective.

Szyjka (2012) says that in early years of educational research the use of the terms "constructivism" and "constructivist" were scarce, but over time has become more popular indicating that educational research has gradually become more and more qualitative in nature. The social constructivist perspective, as influenced by the views of Vygotsky, believes in the social interaction with others when conducting research and is phrased by Kim (2014, p. 6) as indicated below:

> "Vygotsky proposed that socially mediated activities generate higher forms of human consciousness and stressed the mediation of semiotic tools, and especially language, through which human beings' external social activities are transformed into internal psychological functions. Those semiotic tools can mediate social interactions in particular sociocultural contexts, and play an especially important role for human beings in developing collaborative dialogical inquiry."

As science teachers in training the participants of this study should be able to showcase their "internal psychological functions" as external representations as to create "socially mediated activities" in learning situations. This perspective then urges the researcher to actively interact with the research participant and the setting as to create meaning (Kim, 2014). According to Neimeyer and Levitt (2001, p. 2651) conducting research from a social constructivist perspective has got less to do with the actual methods of inquiry and it rather lies in the "philosophy with which the method or technique is used". Neimeyer et al. (2001, p. 2651) classifies research methods as relevant to social constructivism if it can fit into one of the following categories:

a) It elucidates 'local' as opposed to 'universal' meanings and practices.
b) It focuses upon provisional rather than 'essential' patterns of meaning construction.

c) It considers knowledge to be the production of social and personal processes of meaning making.
d) It is more concerned with the viability or pragmatic utility of its application than with its validity per se.

I believe that this study fits into each one of these categories and the research methods utilised during the study reflect and correspond to social constructivism. It is in line with this view of the social constructivist researcher and the requirements which should be met to answer the research question that the study is approached as a simple mixed methods research design. Qualitative research is naturalistic in the sense that it focuses on the natural setting where the interaction of the researched phenomenon (the use of MRs by pre-service science teachers during practice lessons) occurs which in this case will be the science classroom. Nieuwenhuis (2007a, p. 53) mentions that qualitative researchers are:

> "most interested in how humans arrange themselves and their settings and how inhabitants of these settings make sense of their surroundings through symbols, rituals, social roles....".

The quantitative aspects of this study are incorporated due to the nature of the approach, where pre-determined research sub-questions were formulated and at least one of these questions required data where modes of representations were grouped and presence of modes belonging to these groups be quantified. Thus, descriptive statistics were used to describe the qualitative data to some extent. Complementary to this, quantitative aspects were also included as to determine if there are statistically significant differences in the representational competence between physics and chemistry as well as between the use of Non-specialist Words and Expert Words.

The mixed methods approach was also chosen due to the aim of the study to investigate PSTs competence and fluency in the use of MRs during practice teaching sessions, where competence and fluency could both be represented quantitatively and qualitatively, and therefore analysed quantitatively and qualitatively. How and where qualitative and quantitative aspects were incorporated in this study was guided by the research questions below.

The main research question that the study wishes to address is framed as:

How do pre-service science teachers use multiple representations as a pedagogical tool to explain science concepts during their lessons?

The following sub-questions guided the study:

a) *What are the different modes of representation that pre-service science teachers explicitly use during lessons?*

b) *Is there a statistically significant difference between pre-service science teachers' use of multiple representations as well as their level of representational competence and fluency in Physics and Chemistry?*

c) *How do pre-service science teachers engage in translation activities (integration across different modes of representation) in order to explain a specific scientific concept?*

d) *Is there a statistically significant difference in how pre-service science teachers use every day literacy compared to scientific literacy?*

In answering these questions, this study does not aim to look at how the learners in the class make sense of or arrange their understanding (internalisation) of the (possible) use of MRs by the pre-service teachers, but rather how these teachers arrange their own settings and make sense of it while teaching scientific concepts through their PCK. Thus the pre-service teacher is the unit of analysis for this study, while their use of MRs during lesson presentations is the unit of observation. Data was collected using lessons presented by the PSSTs in the form of pre-recorded video lesson presentations and video recorded classroom observed lessons - for the purpose of the study these will collectively be referred to as video recorded lessons and lesson presentations. The next section of this chapter provides a justification for the selection of specific methods and approaches.

3.2.2 Methodological considerations

A Simple Mixed Method Approach

Collecting, analysing, interpreting, and reporting data are all aspects of research design and thus methodological considerations according to Creswell and Clark (2017). Johnson, Onwuegbuzie and Turner (2007) position the mixed method approach in between quantitative and qualitative research, where both extremes are respected while compromises are made to eventually get to a practical and achievable way of approaching research problems combining quantitative and qualitative methods. The authors emphasise that "...mixed methods research is, generally speaking, an approach to knowledge (theory and practice) that attempts to consider multiple viewpoints, perspectives, positions and standpoints (always including the standpoints of qualitative and quantitative research)" (Johnson et al., 2007, p. 113). In recent years the mixed methods approach gained popularity amongst social sciences researchers who view both quantitative and qualitative methods to be of immense value (ibid.). A mixed methods approach would thus be an amalgam of quantitative and qualitative methods.

In the literature there are many statements made and reasons given to rationalise and substantiate the use of a mixed methods approach when conducting research and some of these reasons were summarised by Johnson et al. (2007) to be: validity by means of triangulation and authentication; providing richer data; initiates creative thinking; data sets can complement one another or point out research paradoxes; can help to narrow down or broaden the scope of a study; increased usefulness of findings; verification possibilities, reducing complexity by investigating various perspectives of the same data set; increased instrument reliability; increased confidence in results, to name a few. The authors conclude that in order for a researcher to conduct a far-reaching study the investigation must be process (exploratory) and outcome (confirmatory) oriented. For the purpose of this study a mixed method approach will be viewed as an approach where the mixing, also referred to as the "point of integration" by Schoonenboom and Johnson (2017), takes place in the form of a results point of integration. This implies that the qualitative and quantitative data will be integrated in terms of the results they provide – where the one will play a driving role while the other provides a supportive role.

Kim (2014) argues that researchers working from a social constructivist approach tend to want to work with qualitative research approaches to discover meaning, while Johnson et al. (2007) prefer to view a mixed method approach as applicable to all research paradigms and theoretical frameworks as to create breadth, depth and corroboration in the study.

In order for a researcher to choose a specific mixed methods approach Creswell and Clark (2017) recommend one should consider an approach that best address the problem at hand and best fits the research questions asked in the study. Fischler (2014) proposes that a mixed method approach should be used when the combination of qualitative and quantitative methods will provide a more comprehensible and complete version of the research at hand than using only one approach.

Fischler (2014) suggests that there are four major aspects to keep in mind when choosing a mixed methods study namely: level of quantitative and qualitative interaction; quantitative and qualitative priority; the timing of quantitative and qualitative strands; how and where quantitative and qualitative will be combined. The mixed methods design this study will undertake is the form of a concurrent dependent design (Schoonenboom & Johnson, 2017; Fischler, 2014; Creswell & Clark, 2017), more specifically taking on a *QUAL + quan* design, where a concurrent design is driven by the qualitative data collected. The nature of the concurrent dependent design is to collect the data, in this case the video recorded lessons, and coding the data as a qualitative analysis as set out in Section 3.6.1. The coded data was analysed quantitatively as to support the qualitative data, and in the discussion phase examples of lessons were used to support the quantitative findings. The purpose of this design is to integrate quantitative results and qualitative results obtained from qualitative data in order for the researcher to provide a more comprehensive reflection of the study's results. In this study there is only one point of integration, thus resulting in a *simple* mixed methods design (Schoonenboom & Johnson, 2017). Even though this approach incorporates the quantifying of the qualitative data, the shift to constructivism takes place when analysing and interpreting data qualitatively (Fischler, 2014). In order to decide which role the quantitative and qualitative aspects should play, Fischler (2014) suggests that a mixed methods approach be emergent, while Creswell and Clark (2017) argues that a mixed method approach could either be emergent or fixed. This study will be a fixed mixed method approach, meaning that the qualitative and quantitative methods are predetermined and planned according to the needs of the research questions at hand.

The reasons for the use of the fixed concurrent dependent mixed method design for this study can be formulated as:

- The complementarity of the data if analysed in mixed methods approach
- Expansion of the depth of the study
- Triangulation for increased validity
- It can answer research questions that requires different forms of data
- The researcher feels that there is more credibility in a mixed methods approach
- Qualitative will provide context to the quantitative
- The incorporation of the qualitative data is in line with the constructivist foundation of the study and may point towards unexpected results
- Mixed methods may help to make more relevant suggestions in teacher training endeavours
- The researcher believes that without the addition of qualitative findings the quantitative findings would be arid
- The collection of qualitative data in the form of video recorded lessons observes the PSTs in their natural habitat that makes it open to interpretation but execution may be quantified – thus allowing for the researcher to look at competence and fluency in their PCK.

The final results were reported in two phases, first the results relevant to each research question was analysed and summarised from a quantitative and/or a qualitative point of view depending on the requirements of the question. The final step of the fixed concurrent dependent mixed method design of this study was for quantitative results to be interpreted, together with the qualitative data, and finally a discussion by means of examples on the extent to which the qualitative explains the quantitative took place (Creswell et al., 2017).

The role of the researcher during data collection and interpretation is that of observer as participant where the observer remains uninvolved during data collection but may look for ways of interpreting what is being observed. This is in line with the social constructivist researcher. The justification for video recorded data collection takes place in the next section of this chapter.

3.3 Data Collection Methods

Derry, et al. (2010, p. 4) state: “Rapid development and widespread availability of affordable, usable, high-quality video technology is transforming the practice of learning science research. Because new video technologies provide powerful ways of collecting, sharing, studying, presenting, and archiving detailed cases of practice to support teaching, learning, and intensive study of those practices, many learning science research projects now incorporate a substantial video component”. Dalland, Klette and Svenkerud (2020) says that video analysis has become increasingly more popular and important to educational researchers over the past years – especially those researchers who are interested in analysing complex interactions in classroom phenomena. Video analysis is also a tool that can be used in conjunction with various research methodologies, especially in the teaching sciences (Derry et al., 2010). Video recording of data offers close and in-depth documentation and observation, makes it possible to analyse data from different perspectives for multiple purposes, take into account time scales, and archive recordings for later use or for the purpose of studies conducted by other researchers (Derry et al., 2010; Dalland et al., 2020). It allows researchers to "watch, code, and interpret recordings a number of times” (Dalland et al., 2020, p. 53) and this is the main reason why many researchers prefer video recordings to attempt to investigate and understand the interactions in a classroom such as learning, teaching and collaborating. However, the use of video recordings brings along its own set of challenges, the biggest issue being ethics (Derry et al., 2010).

The data collection via pre-recorded video lesson presentations and video recorded classroom observed lessons was done on a number of occasions. The data collection process and the ethical clearance obtained to do so is described in more detail below. For each occasion, permission to conduct and complete the data collection was requested from the participant. Below is a detailed step-by-step layout of the data collection process:

1. Permission was requested and granted from The Western Cape Education Department (WCED) to conduct the research. This was done via email. (Addendum C)
2. Permission was requested and granted from Stellenbosch University as an Institution to conduct the research. This was done via an online application. (Addendum B)
3. Permission was requested and granted from the Research Ethics Committee (REC) (Human Research) for ethical clearance at Stellenbosch University. This was done via an online application. (Addendum D)

4. Permission was asked from the identified groups of the target population. This was first done through a verbal communication with the groups in their classes and was followed up with an email. The potential participants had access to a hard-copy and electronic version of the consent form they had to sign if they volunteered to participate in the study. (Addendum E)
5. Those participants who granted permission was then either asked to provide their pre-recorded video lesson presentations or asked to give a letter to their mentors and respective schools where they will conduct their practice teaching sessions to ask for permission to have the study conducted on the premises. The letter contained the required information as requested by the University of Stellenbosch's research and ethics policy. This letter was provided to the participants via email and they had to provide the school with a copy of the letter. Alongside the letter was a copy of the consent given by the WCED. (Addendum F)
6. The schools who gave permission had to provide the parents of the learners' to be taught by the pre-service teachers with notifying consent forms. The manner of this communication was up to the schools to decide and could either be hard copies of the letter or electronic versions.
7. It is only after this step that the data collection was conducted as set out and summarised in Table 3.1.

Below, Table 3.1 is an overview and elaboration of the data collection methods and the processes followed to collect the data.

Table 3.1: Overview of data collection method and process

Method	**Process**
Classroom observations with video recordings and note taking.	• PST provides written consent to participate in the study. • PST choose topic of the lesson and prepare and present accordingly. • Lesson observed and video recorded by researcher. • Recordings with topics not classified as Physics or Chemistry eliminated from sample.
Pre-recorded video lesson presentations	• PST provides written consent to participate in the study. • PST prepare self-recorded lesson presentation on prescribed theme in curriculum. • Submit pre-recorded lesson to module facilitator who handed these over to me. • Recordings with topics not classified as Physics or Chemistry eliminated from sample

It is important for this study to mention that the pre-service science teachers as participants were not informed on the detailed focus of the research before the lesson presentation, only the title of the study was indicated, since it may have influenced the way they plan and structure their lesson presentations – thus interfering with their current PCK. Since the aim is to observe participants in a naturalistic setting, it may have influenced the data if the participants were aware of the in-depth details of the study. Alongside this, pre-determined lesson plans were also not provided to the pre-service teachers as to not interfere with their PCK and leave the preparation process to run its natural course. The role of the observer was that of observer as participant where the observer remains uninvolved but may look for ways of interpreting what is being observed.

All participants are obligated to provide written consent before participating in the study. After this was provided the data was collected in the form of video recorded lessons. Lessons conducted on topics classified as Chemistry or Physics related concepts according to the CAPS curriculum were analysed for this study. Video recorded lessons on topics such as Biology and Earth Sciences were eliminated from the study and such data was destroyed permanently.

Classroom observation video recordings were conducted by myself during the lessons presented by the pre-service teachers at Stellenbosch University and the selected schools where they were placed during their practice teaching experience.

Note taking during lesson observations were done in the form of a mixed method combining running records and structured observation with the focus on the use of the MRs. This is to make sure that description of and interpretation as well as reflection on what is observed can take place (Nieuwenhuis, 2007b, p. 92)

The pre-recorded video lesson presentations that were analysed made up a part of the portfolio of evidence the pre-service science teachers had to hand in during the course of their studies for the enrolled module. The themes and scientific concepts of the lesson presentations were pre-determined by the module facilitator at the university, and the students were encouraged to demonstrate a practical application of the content. However, it was up to the student to explain the concepts - thus it was open-ended as to the representational modes that may be used to present the concept. Each pre-recorded video lesson presentation was handed in by the pre-service science teachers with the purpose of it representing a real lesson in mind – exactly what and how they plan to develop and facilitate the scientific concept to their learners.

Lessons conducted on topics classified as Chemistry or Physics related concepts according to the CAPS curriculum were identified using the CAPS curriculum as reference framework and then analysed for this study. This will be elaborated on later in this chapter.

3.4 Sampling: Population and Research Sites

It is important to describe the setting as to place boundaries on the case to prevent it from being too broad or unfocused. The setting was used to identify the potential participants for the study and those potential participants were approached by me.

The setting of this study can be described as investigating how students at Stellenbosch University enrolled in either a Natural Sciences module in a Bachelor of Education program or a Physical Sciences module in a Post Graduate Certificate in Education use multiple representations (MRs) to explain science concepts. These students will ultimately teach Natural Sciences in the Senior Phase (Grade 7 – 9) or Physical Sciences in the Further Education and Training phase (Grade 10 – 12), and would need to develop their skills as they engage with the curriculum in a science teaching classroom. All students enrolled for these modules were approached to participate in the study, while only those who agreed to participate and signed the consent forms were contacted to arrange for data collection dates. A distinction was be made between Physics and Chemistry during the presented lessons and data analysis as the pre-service teachers had to present a specific topic that can only be relevant to either physics or chemistry as set out in the CAPS curriculum of South Africa to be deemed valid participants. Of the participants who agreed to participate, those who chose to present lessons from the Biology or Earth Sciences section of the Natural Sciences CAPS curriculum were eliminated as such data could not be classified as Chemistry or Physics when the framework of the CAPS curriculum was used. For initial coding purposes the participant were divided into six groups (A, B, C, D, E and F) and described as set out in Section 3.4 and Module 4.

3.4.1 Pre-recorded video lesson presentations

The population of the pre-recorded video lesson presentations as a unit of analysis comprised of three groups: second year, third year and final year pre-service science teachers enrolled in a Natural Sciences Education module at Stellenbosch University. Each group had to complete a project on a prescribed science concept identified from the South African CAPS curriculum at the end of a unit. The science concept in question was determined by the module facilitator as part of the portfolio of evidence each participant had to submit in line with the requirements set out to pass the module. Four different science concepts were prescribed to different groups (see below). The pre-recorded video lesson presentations they had to develop had to illustrate how they would present the concept to a hypothetical class at a school when teaching Natural Sciences as a subject. They also had to explain what was observed using different representations. The lesson presentations were video recorded either during class at the university by the module facilitator or by the pre-service science teachers themselves and submitted to the module facilitator. The following themes and population numbers were recorded and analysed.

Table 3.2: Pre-recorded video lesson presentations themes and population for different groups of pre-service science teachers enrolled in a Natural Sciences Education or Physical Sciences Education module at Stellenbosch University.

	Theme (science concept)	**Assignment as set out by facilitator**	**Group**	**Population**
Physics Lesson Presentations	Series/Parallel Circuits	Work with a classmate to design a project to apply some of the principles in electricity that you have learnt. Apparatus (kit) will be supplied. Demonstrate how it works and explain how it works. Make a video recording in which you use a simulation. **See Addendum G for complete assignment*	Group A	n = 40
	Visible Light	Refer to chapter 4 - Visible light in the textbook Science-Grade-8B-English-Learners. It gives you an idea where the content fits in with the CAPS and what you should be familiar with when teaching Senior Phase Natural Sciences. 1. Draw up a lesson plan on any of the topics in the chapter (include appropriate content and indicate your teaching approach and indicate all the materials and resources that you will use). 2. Draw up an assessment activity using Socrative (the questions must cover different cognitive levels). 3. Make a video recording of the lesson in which you explain the key concepts (you must focus on the micro-level when explaining a phenomenon, e.g. how does a rainbow form?). **See Addendum H for complete assignment*	Group B	n = 34

Chemistry Lesson Presentations	Matter and Materials	Choose a section from Senior Phase Natural Sciences and plan a lesson for a Grade 7/8 class. You must do a practical demonstration of any of the concepts out of the lesson and make a video recording. **See Addendum I for complete assignment*	Group C	n = 38
	Chemical Reactions	Refer to the textbook Science-Grade-9A-English-Learners on (online platform) – Chapters 2, 3 & 4. In chapter 2 certain key concepts are explained. Choose an application in chapter 3 or 4 to address these key concepts. You must prepare a maximum of 10 slides with an explanation of each included (audio). **See Addendum J for complete assignment*	Group D	n = 43

The results obtained for these groups can be found in Chapter 4, Sections 4.2.1 – 4.2.4.

3.4.2 Classroom observation video recordings

At most South African universities and tertiary institutions students studying education have to complete two practical practice teaching endeavours during their final years of studying. For the second, third and final year B.Ed. students this will take place during that respective year of their studies while it takes place in the first year of studies for PGCE students. The first practical experience entails micro-teaching sessions at this university where local schools send learners to attend short classes (approx. 30min) presented by these PSTs on different subjects. The second practical experience the PSTs gain would be during a 9-week practice teaching experience where they are placed at schools in close proximity to the university (on average about 50 km radius) and are expected to teach at the school alongside qualified and experienced mentor teachers.

Video recordings of these lessons presented took place during micro-teaching lessons at the university and teaching practice lessons at selected schools. There was no distinction made between lessons presented during micro-teaching and practice teaching sessions. The themes of the lessons were not prescribed but chosen by the pre-service teachers themselves after consultation with the relevant school. The following themes and population numbers were recorded and analysed.

Table 3.3: Classroom observation video recordings themes and population for different groups of pre-service science teachers in a Natural Sciences Education or Physical Sciences Education module at Stellenbosch University.

	Theme(s) (science concept) chosen by the PSSTs	**Assignment as set out by facilitator**	**Group**	**Population**
Physics Lesson Recordings	electricity (conductors and insulators; circuits; energy); renewable energy sources; contact and non-contact forces	Each PSST must present a minimum amount of lessons during their practice teaching experience at the schools, some of which had to be evaluated by a qualified teacher at the school. These lessons were recorded during one of these sessions and the topic chosen was determined by the respective schools and their teachers and where they're at in the curriculum. No prescribed assignment was used, however the PSST did have access to the marking criteria used to evaluate lessons.	Group E	n = 8
	conservation of mechanical energy		Group E	n = 1
Chemistry Lesson Recordings	metals and non-metals		Group F	n = 1
	stoichiometric calculations; solutions and concentrations		Group F	n = 2

The results obtained for these groups can be found in Chapter 4, Sections 4.2.5 – 4.2.6. In the next section the discussion of the ethical considerations I had to take into account when conducting this study is provided.

3.5 Ethical Considerations

Video recordings and voice recordings of pre-service teachers are needed to collect the data for this study. Ethical clearance and pre-service teacher consent was obtained to conduct this study.

Derry et al. (2010, p. 34) summarised the following aspects to be in place for an ethical treatment of people participants:

> "...we briefly characterize such treatment as requiring that subjects be fully informed about the purposes, risks, and potential reward of the research; that given this information they participate voluntarily; that they be allowed to comfortably withdraw their participation during a study without penalty; and that their expectations and rights to privacy and confidentiality be honoured"

Hill (2005) lists four ethical considerations that a researcher should account for, namely: the welfare of the participants; protection of participants; participants should be made to feel good about participating and having contributed to social research; and lastly, choice of participation.

All potential participants were approached in a fair and informative manner and participation took place voluntarily. Participants were made aware of the potential contribution of the study to educational research in a South African context as to highlight the service they are providing to their community through participation. The participants will remain anonymous throughout the study and participation in the study posed no or minimal risk to participants. The respective schools where the practice teaching sessions will take place also had to give permission for the recordings – the study however did not record the learners to be taught by the student teachers. Both the participants and the schools were allowed to opt out at any point during the study and was made aware of this. If this was the case it was discussed with the relevant party and put in writing. To conduct this research I applied for and was granted permission by Stellenbosch University (SU) as an institution, the Research Ethics Committee (REC) (Human Research) for ethical clearance at the University, as well as the Western Cape Education Department (WCED). Please see Addenda B-F for Permission and Consent Forms issued for this study. Once all the video recordings were collected in an ethical and considerate manner, the data had to be analysed, as discussed in the next section of this chapter.

3.6 Data Analysis Procedures

A mixed method research methodology was used to analyse the data - which allows for qualitative data to be collected and analysed to produce quantitative as well as qualitative results.

3.6.1 Initial Coding and Analysis of Video Data

Figure 3.1 below was used to formulate the approach that guided the analysis tool (Table 3.4) Figure 3.1 was discussed and rationalised in Section 2.5. From this model in Figure 3.1 it is evident that science teachers should be competent in 5 different modes of representation namely Graphical, Experimental, Symbolic, Non-specialist Words as well as the use of Expert Words. The connections between the different modes in Figure 3.1 implies fluency – translating from one to the other.

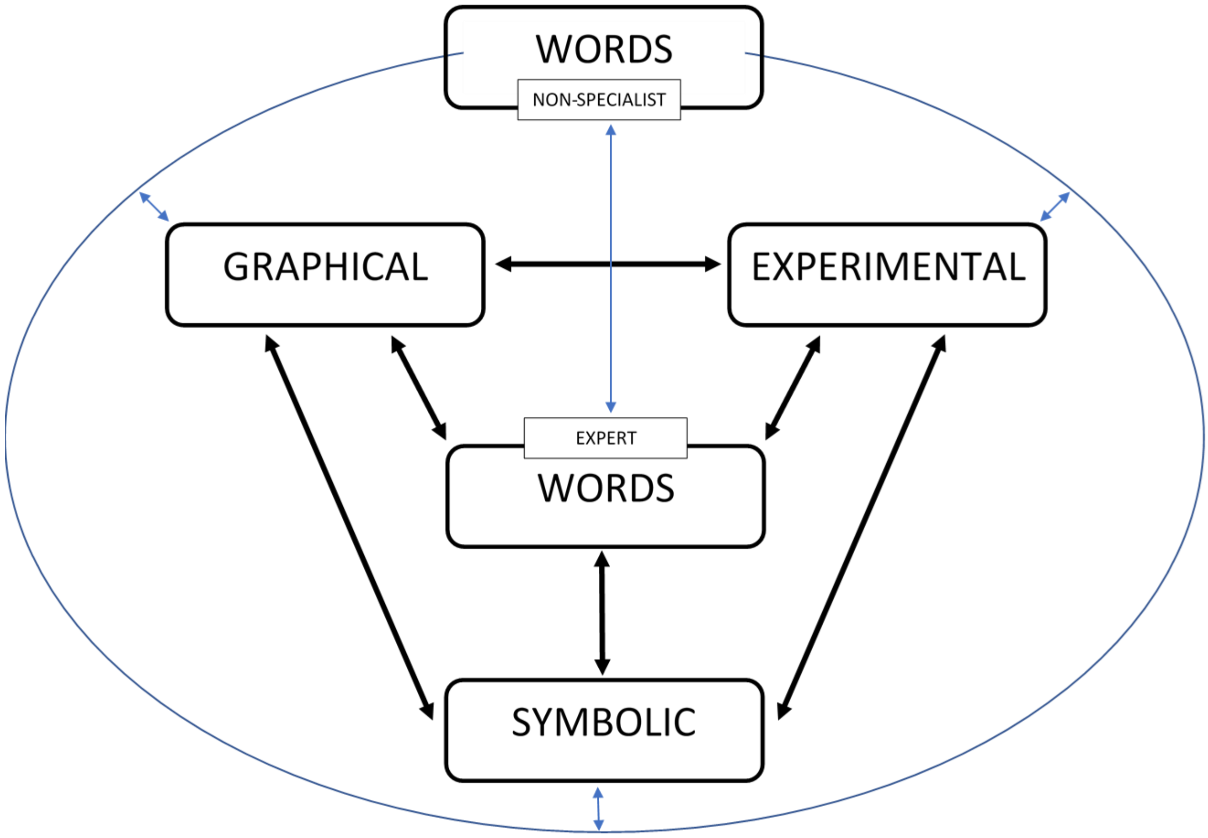


Figure 3.1: A representation model indicating categories of competence and fluency (adapted from Lesh & Doerr, 2003 and Maree & Edwards, 2019) – distinguishing between the use of science specific language (expert) and everyday language (non-specialist).

Lesh and Doerr (2003) argues that it is important that accurate translation between different modes take place otherwise inconsistencies in thinking and understanding may go unnoticed when using different representations. The layout of this model emphasise the idea that there is interaction between all of the different modes of representation (competence and fluency), but that all of them lies within the context of the Words used. The use of Expert Words was placed at the centre of the model as to imply that all of the other modes come together at the focal point of scientific literacy and the use of content-specific words that is used in a science contexts. The use of Non-specialist Words, or everyday language, was placed on the outside surrounding the other modes of representation as to suggest that the use of everyday literacy is embedded into each one of the other representations and that one won't be able to interpret or explain any of those without a sense of everyday language. Placing the use of Words (Expert and Non-specialist) at the centre and the circumference of the model respectively points towards the immense importance of language and literacy in this Science setting.

From the representational modes in Figure 3.1 the following levels was set out to analyse the qualitative data to eventually allow for the conversion to quantitative data. In line with the analysis tool (Table 3.4) competence was analysed either as *inappropriate, partially appropriate* or *appropriate* use of a specific representational mode, whereas fluency was analysed either as the use of a mode that is *not linked, partially linked* or *is linked* to other modes of representation.

Table 3.4: Representational Competence and Fluency Levels

Type of representation	**Use of representation**		
	Low level **1**	**Medium level** **2**	**High level** **3**
Graphical (graphs, diagrams, simulations)	**Inappropriate** graphical illustration that is not linked to the experimental, symbolic or word representation modes. Student demonstrates incorrect scientific understanding of concepts.	**Partially appropriate** graphical illustration that is partially linked to the experimental, symbolic or word representation modes. Student demonstrates partially correct scientific understanding of concepts.	**Appropriate** graphical illustration that is linked to the experimental, symbolic or word representation modes. Student demonstrates correct scientific understanding of concepts.
Experimental (hands-on, model building, demonstrations, phenomenological, sensory)	**Inappropriate** experimental illustration that is not linked to the graphical, symbolic or word representation modes. Student demonstrates incorrect scientific understanding of concepts.	**Partially appropriate** experimental illustration that is partially linked to the graphical, symbolic or word representation modes. Student demonstrates partially correct scientific understanding of concepts.	**Appropriate** experimental illustration that is linked to the graphical, symbolic or word representation modes. Student demonstrates correct scientific understanding of concepts.
Symbolic (mathematical equations, formulae, chemical equations, quantitative)	**Inappropriate** symbolic illustration that is not linked to the experimental, graphical or word representation modes. Student demonstrates incorrect scientific understanding of concepts.	**Partially appropriate** symbolic illustration that is partially linked to the experimental, graphical or word representation modes. Student demonstrates partially correct scientific understanding of concepts.	**Appropriate** symbolic illustration that is linked to the experimental, graphical or word representation modes. Student demonstrates correct scientific understanding of concepts.

Non-specialist Words (verbal, written, analogy)	**Inappropriate** use of words that is not linked to the experimental, symbolic, graphical or expert words representation modes. Student demonstrates incorrect scientific understanding of concepts.	**Partially appropriate** use of words that is partially linked to the experimental, symbolic, graphical or expert words representation modes. Student demonstrates partially correct scientific understanding of concepts.	**Appropriate** use of words that is linked to the experimental, symbolic, graphical or expert words representation modes. Student demonstrates correct scientific understanding of concepts.
Expert Words (verbal, written, analogy)	**Inappropriate** use of words that is not linked to the experimental, symbolic, graphical or non-specialist words representation modes. Student demonstrates incorrect scientific understanding of concepts.	**Partially appropriate** use of words that is partially linked to the experimental, symbolic, graphical or non-specialist words representation modes. Student demonstrates partially correct scientific understanding of concepts.	**Appropriate** use of words that is linked to the experimental, symbolic, graphical or non-specialist words representation modes. Student demonstrates correct scientific understanding of concepts.

As part of the qualitative analysis each mode was coded with a value (0 = no evidence; 1 = low level; 2 = medium level; 3 = high level) and these values were captured in a spreadsheet. No attempt at any representation was indicated as zero (0). The frequency of each level for a specific representation (Graphical, Experimental, Symbolic, Non-specialist Words, Expert Words) was tallied and expressed as a percentage and functioned as a form of descriptive statistics. A zero coding thus indicates that no evidence for the use of a specific mode of representation could be found (no competence). A coding of 3 was assigned to a mode of representation that showcases competence and was used in conjunction with at least 2 other modes of representation as to promote fluency. A coding of 2 was assigned when a partially adequate level of competence was evident and linked to none or only one other representational mode. A coding of 1 was assigned to a representation where no competence or low levels of competence was evident for an attempt, in spite of this mode being linked to other modes of representation. A coding of 0 was assigned when there was no attempt made at using a specific representational mode. In Table 3.5 below the codes which were assigned during the initial coding phase can be found, and was used as indicated in Addendum K.

Table 3.5: Coding used for Representational Competence and Fluency Levels

Type of representation	**Competence & Fluency Coding**			
	No attempt	**Low level 1**	**Medium level 2**	**High level 3**
Graphical	Graphical 0	Graphical 1	Graphical 2	Graphical 3
Experimental	Experimental 0	Experimental 1	Experimental 2	Experimental 3
Symbolic	Symbolic 0	Symbolic 1	Symbolic 2	Symbolic 3
Non-specialist Words	NS Words 0	NS Words 1	NS Words 2	NS Words 3
Expert Words	Expert Words 0	Expert Words 1	Expert Words 2	Expert Words 3

This coding analysis was repeated separately for the four groups of participants that participated through lesson presentations and was separated according to topic. This enabled me to distinguish between results obtained for Physics and Chemistry topics as set out by the CAPS Curriculum. The coding analysis was also done separately for the video recorded lessons as to distinguish between Physics and Chemistry according to the topics set out by the CAPS Curriculum. Thus six sets of video recorded data (Groups A, B, C, D, E and F) were analysed with the same coding analysis tool as set out in this chapter. Coding results are summarised and discussed in Chapter 4 of the study. A secondary coding was conducted on the data as set out in the next section under qualitative data analysis and descriptive statistics and quantitative analyses took place as set out in the quantitative data analysis section following the next. In Chapter 1, Figure 1.2 presents an overview of the data analysis and interpretation process.

3.6.2 Qualitative Data Analysis

For the initial qualitative analysis each mode was coded with a value (0 = no evidence; 1 = low level; 2 = medium level; 3 = high level) as set out in Table 3.5 and these values were captured in a spreadsheet. No attempt at any representation was indicated as zero (0). The frequency of each level for a specific representation (graphical, experimental, symbolic, non-specialist words, expert words) was tallied and expressed as a percentage (Tables 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6). An example of how a lesson was coded can be found in Addendum K.

A Secondary coding was done on the results of the first codes in an attempt to investigate the fluency between different representational modes for physics and chemistry respectively. The codes assigned in this step was for the different modes of representation as indicated in Table 3.6 below:

Table 3.6: Coding used for Indication of Representational Fluency

Representational Mode	Code Assigned
Graphical	G
Experimental	E
Symbolic	S
Non-Specialist Words	NS
Expert Words	X

For those lessons that qualified (as set out in Chapter 4) the secondary codes were combined in the order G, E, S, NS, X if present (Addendum H). The different code combinations were identified and tallied for Physics and Chemistry and expressed as a frequency of occurrence (Tables 4.19 and 4.20).

3.6.3 Quantitative Data Analysis

After the initial and secondary coding phases took place, the coded data was used to describe the results quantitatively as well. The Chi-Square Test was used to determine any statistically significant difference between representational competence in Physics (n=83) and Chemistry (n=84). The same analysis was completed for each one of the Representational Modes (Graphical; Experimental; Symbolic; Non-specialist Words; Expert Words).

The Chi-Square Test was again conducted to determine any statistically significant difference between representational competence between the Non-specialist Words and Expert Words representational modes. The same analysis was completed for Physics (n=83), Chemistry (n=84) and Physics and Chemistry combined (n=167).

Jim Frost (2017) explains that the chi-square test of independence may be used when a researcher wants to compare expected and observed data distributions for different categories, assuming a null-hypothesis. The null-hypothesis states that there are no relationships between the variables. If the chi-square value is greater than or equal to 7.815 ($p \leq 0.05$) for a data set with 3 degrees of freedom (df=3) a statistically significant chi-square value is obtained and the null-hypothesis is rejected by the data distribution – thus an alternative hypothesis is accepted which states that there are relationships between the two categories of data (ibid.). Should the chi-square value be smaller than 7.815 ($p \geq 0.05$) the null-hypothesis is accepted and this points towards no relationships between the data categories analysed (ibid.).

The combination of the qualitative analyses and quantitative analyses results will allow me to develop a valid study with reliable results by means of triangulation as elaborated on briefly in the next section.

3.7 Validity and Reliability in Research

Zohrabi (2013) mentions that the use of mechanical recordings during data collection, as in this case the video recordings of the lessons presented, improves the reliability of the study because the data can be preserved and independent researchers may independently attempt to replicate the study. Johnson et al. (2007) argued that when using a mixed methods research design, the validity of the study is strengthened by means of triangulation. Webb, Campbell, Schwartz, and Sechrest (1966) refers to this as across-method triangulation and in the case of this specific study what Denzin and Lincoln (2005) calls simultaneous methodological triangulation, which indicates the use of multiple methods at the same time to study a research problem. Triangulation by using mixed methods to analyse the data will allow me to construct more meaningful and richer interpretations of the phenomenon, namely the use of MR by pre service science teachers, and the setting of the inquiry as a real-world context. This will allow me to be more confident in my findings for this study. According to Johnson et al. (2007) triangulation could highlight points of contradiction and inconsistency and this could lead to creative ways of explaining these, or adjusting the study as to better create points of convergence, if possible. Nieuwenhuis (2007c, p. 122) concludes that triangulation is the use of “multiple lines of sight” and thus reflects a richer interpretation of the reality in which the study is grounded.

3.8 Conclusion

This chapter discussed and substantiated the details of the research design and methodology of this simple mixed methods study. The participant groups and setting were described and the ethical considerations pertaining to the participants and the setting were laid out. Data collection and analyses procedures and tools were described and the point of integration in the mixed methods study was discussed, while the qualitative and quantitative aspects of the study were described in detail. Lastly, the reliability and validity of the study was discussed. In the next Chapter, I present the results and data analyses of the data obtained during the study.

CHAPTER 4: RESULTS AND DATA ANALYSIS

4.1 Introduction

As discussed in Chapters 1 and 3, the main research question this study aimed to investigate was:

> How do pre-service science teachers use multiple representations as a pedagogical tool to explain science concepts during their lessons?

The following sub-questions guided the study and the analyses of data sets to follow in this chapter:

a) What are the different modes of representation that pre-service science teachers explicitly use during lessons?

b) Is there a statistically significant difference between pre-service science teachers' use of multiple representations as well as their level of representational competence and fluency in Physics and Chemistry?

c) How do pre-service science teachers engage in translation activities (integration across different modes of representation) in order to explain a specific scientific concept?

d) Is there a statistically significant difference in how pre-service science teachers use every day literacy compared to scientific literacy?

This chapter presents and organises the quantitative and qualitative results and data analyses obtained and conducted from the video recorded lesson presentations. The discussion of this data is recorded in Chapter 5 and includes qualitative evidence to support results. Ivankova, Creswell and Plano Clark (2007) explain that a mixed methods approach allows the researcher to not just look at the "what" but also the "how" and the "why" and in doing so allows for the gaining of a more complete interpretation and understanding of the research problem and research results at hand. The chapter starts with a summary of the initial coding results for each of the different groups, where noteworthy observations were pointed out and emphasised by means of descriptive statistics. Thereafter each research sub-question was addressed through four different sections (Different Modes of Representation Used Explicitly; Representational Modes Used in Chemistry and Physics; Integration Across Different Modes of Representation; The Use of Everyday Literacy vs Scientific Literacy) with appropriate and relevant statistical analyses and qualitative analyses as to finally address the main research question this study aims to shed light on.

In similar ways as demonstrated below in Section 4.2.1 for Electric Circuits, different representational modes can be identified for teaching and explaining each one of the science concepts covered in the science curriculum. Each one of these concepts also require science context specific words (expert words) as to allow a member of the SCoP to communicate with other members, where the use of these terms allow each member to become more integrated into and identify with this community. These expert words can be identified and defined in accordance with the science concept under investigation.

In order for these representational modes to be identified from the video recorded lessons the data was coded as set out in Section 4.3 below. After the initial coding was completed the codes for Groups A, B and E were combined and collectively referred to as the Physics data, while the codes for Groups C, D and F were combined and collectively referred to as the Chemistry data.

4.2 Summary of Initial Coding Results for Different Groups

For the qualitative analysis an initial coding took place where each mode used during a lesson presentation was coded with a value (0 = no evidence; 1 = low level; 2 = medium level; 3 = high level) as set out in Figure 3.5 (Chapter 3) and these values were captured in a spreadsheet. No attempt at any representation was indicated as zero (0). The frequency of each level for a specific representation (graphical, experimental, symbolic, non-specialist words, expert words) was tallied and expressed as a percentage as shown in the Tables to follow (Tables 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6).

4.2.1 GROUP A LESSON PRESENTATIONS: SERIES/PARALLEL CIRCUITS (n=40)

Group A consisted out of 40 participants who had to present a lesson on series and/or parallel circuits, this topic is categorised as part of the Physics section in the CAPS curriculum. These 40 participants were part of a group of second year undergraduate PSSTs at Stellenbosch University, which means they still have two more years to complete after having finished the current year of studies before qualifying as a professional teacher of science.

In Addendum K an example of how the lessons was coded can be found. Each recorded lesson was coded and results were inserted into an Excel spreadsheet as to capture the coded values. These coded values was then tallied out of the total of 40 participants and this was expressed as a percentage for each level and representational mode as set out in Table 4.1 below.

Wong and Chu (2017) identified five conceptual elements when the researchers analysed various textbooks to teach electric circuits in an introductory phase, namely: object (electric charge and charge-carriers such as electrons), nature (characteristics such as rate of flow of charge), cause (or effect such as potential difference), mathematical equations, and circuit condition (components of the circuit and whether the circuit is working or not). These five conceptual elements may be represented in various ways. For instance, electric charge may be represented by means of definition (Words), a mathematical equation (symbolic), a simulation (graphical) and a demonstration (experimental).

Another example may be the condition of the circuit: building the actual model of the circuit and opening and closing the switch (experimental), then carrying on with the use of a simulator to change the battery's potential difference and plotting the results on a graph (graphical) where after the gradient of the graph and a mathematical equation such as Ohm's Law may be used to explain relationships between variables (symbolic) all the while using specific terms such as current, potential difference and resistance (expert words) and general words such as influence, relate and affect (non-specialist words) to link all of the different representations together.

Graphical representations obtained for this participant group included graphs, diagrams and simulations. Experimental representations obtained included hands-on, model building, demonstrations, phenomenological and sensory experiences. Symbolic representations included mathematical equations, formulae, chemical equations and quantitative aspects. Non-specialist word representations included verbal and written communications. Expert word representations included verbal and written communications.

Expert words in this topic identified from the CAPS curriculum document Grade 10-12 includes but is not limited to (see Addendum L): electrical conductors; semi-conductors; insulators; potential difference; work; charge; voltage; battery; current; emf; terminal; circuit; resistors; switch; ammeter; voltmeter; ampere; coulomb; circuit diagram; conventional; circuit element; series; parallel; ohm; electrons; particles; kinetic energy; electrical energy; chemical potential energy; inversely proportional; Ohm's Law; ohmic and non-ohmic conductors; power; watts; electrical power; joules; kilowatt hour; cost of electricity usage; crocodile clips; bulb holders; internal resistance; external circuit; equivalent resistance; branch; short circuit; open circuit; lost volts. The identification of the expert words from the CAPS curriculum document was not done for each any every topic as this is just a demonstration of what could be done. The use (or misuse) of expert words will be discussed further in Chapter 5.

During the initial coding of the video recorded lessons the following results were obtained for Group A participants:

Table 4.1: Percentage representational competence and fluency at each level for pre-service science teachers in Group A

Level	Graphical %	Experimental %	Symbolic %	Non-specialist Words %	Expert Words %
no attempt	12,5	7,5	77,5	5,0	17,5
low-level	22,5	35,0	12,5	22,5	67,5
medium-level	25,0	47,5	5,0	35,0	12,5
high-level	40,0	10,0	5,0	37,5	2,5

The data can also be presented in the form of a bar graph as to visually represent how the different representational modes and their respective levels of competence and fluency compare for Group A participants:

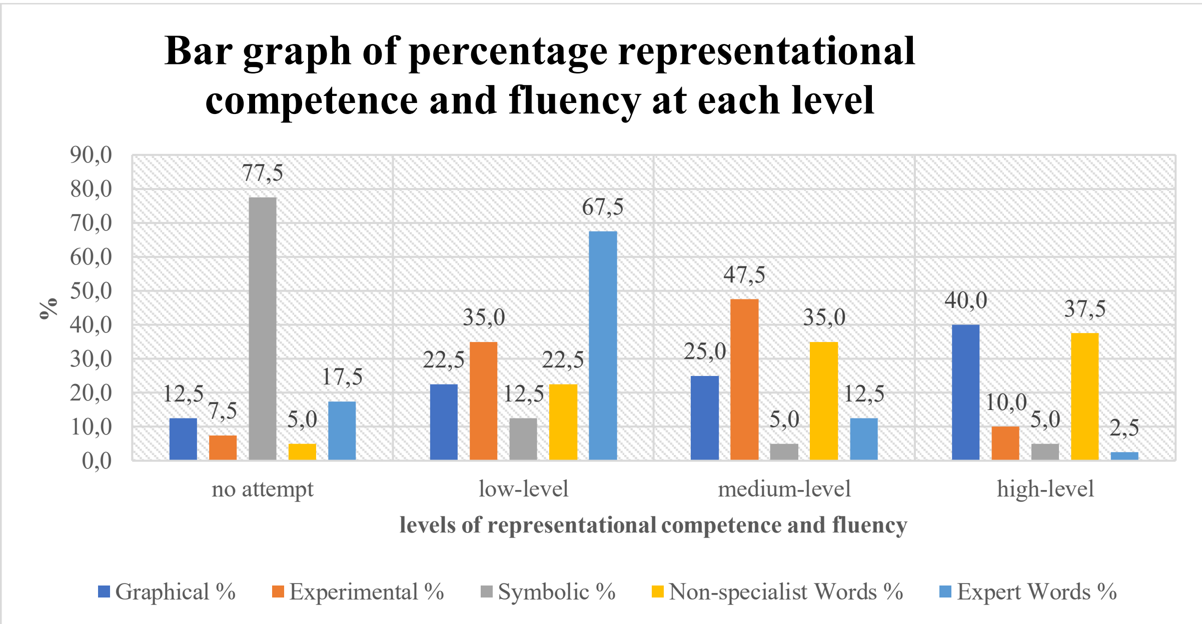


Figure 4.1: Bar graph of percentage representational competence and fluency for pre-service science teachers in Group A

4.2.2 GROUP B LESSON PRESENTATIONS: VISIBLE LIGHT (n=34)

Group B consisted out of 34 participants who had to present a lesson on visible light, this topic is categorised as part of the Physics section in the CAPS curriculum. These 34 participants were part of a group of fourth (and final) year undergraduate PSSTs at Stellenbosch University which means they should, after having finished the current year of studies, qualify as professional teachers of science.

During the initial coding of the video recorded lessons the following results were obtained for Group B participants:

Table 4.2: Percentage representational competence and fluency at each level for pre-service science teachers in Group B

Level	Graphical %	Experimental %	Symbolic %	Non-specialist Words %	Expert Words %
no attempt	5,9	50,0	97,1	0,0	0,0
low-level	11,8	11,8	0,0	5,9	23,5
medium-level	47,1	29,4	2,9	29,4	52,9
high-level	35,3	8,8	0,0	64,7	23,5

The data can also be presented in the form of a bar graph as to visually represent how the different representational modes and their respective levels of competence and fluency compare for Group B participants:

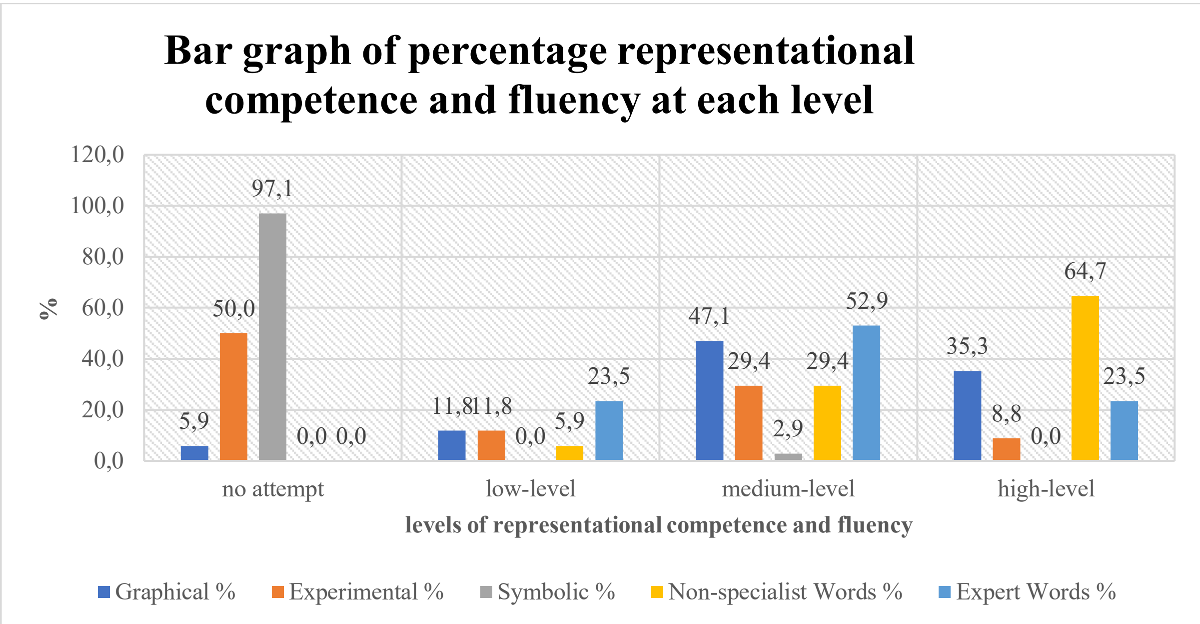


Figure 4.2: Bar graph of percentage representational competence and fluency for pre-service science teachers in Group B

4.2.3 GROUP C LESSON PRESENTATIONS: MATTER AND MATERIALS (n=38)

Group C consisted out of 38 participants who had to present a lesson on matter and materials, this topic is categorised as part of the Chemistry section in the CAPS curriculum. These 38 participants were part of a group of second year undergraduate PSSTs at Stellenbosch University, which means they still have two more years to complete after having finished the current year of studies before qualifying as a professional teacher of science.

During the initial coding of the video recorded lessons the following results were obtained for Group C participants:

Table 4.3: Percentage representational competence and fluency at each level for pre-service science teachers in Group C

Level	Graphical %	Experimental %	Symbolic %	Non-specialist Words %	Expert Words %
no attempt	78,9	0,0	94,7	0,0	23,7
low-level	2,6	21,1	2,6	18,4	34,2
medium-level	18,4	44,7	2,6	44,7	36,8
high-level	0,0	34,2	0,0	36,8	5,3

The data can also be presented in the form of a bar graph as to visually represent how the different representational modes and their respective levels of competence and fluency compare for Group C participants:

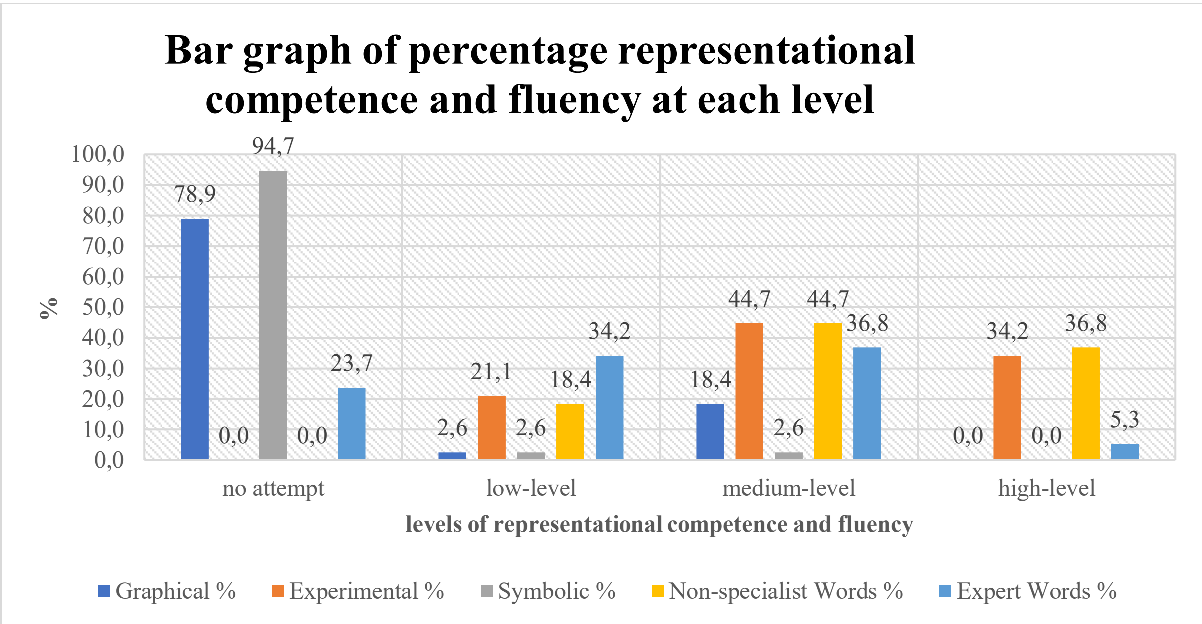


Figure 4.3: Bar graph of percentage representational competence and fluency for pre-service science teachers in Croup C

4.2.4 GROUP D LESSON PRESENTATIONS: CHEMICAL REACTIONS (n=43)

Group D consisted out of 43 participants who had to present a lesson on Chemical Reactions, this topic is categorised as part of the Chemistry section in the CAPS curriculum. These 43 participants were part of a group of third year undergraduate PSSTs at Stellenbosch University, which means they still have one more year to complete after having finished the current year of studies before qualifying as a professional teacher of science.

During the initial coding of the video recorded lessons the following results were obtained for Group D participants:

Table 4.4: Percentage representational competence and fluency at each level for pre-service science teachers in Group D

Level	Graphical %	Experimental %	Symbolic %	Non-specialist Words %	Expert Words %
no attempt	11,6	20,9	0,0	0,0	0,0
low-level	32,6	46,5	25,6	2,3	25,6
medium-level	44,2	27,9	53,5	30,2	60,5
high-level	11,6	4,7	20,9	67,4	14,0

The data can also be presented in the form of a bar graph as to visually represent how the different representational modes and their respective levels of competence and fluency compare for Group D participants:

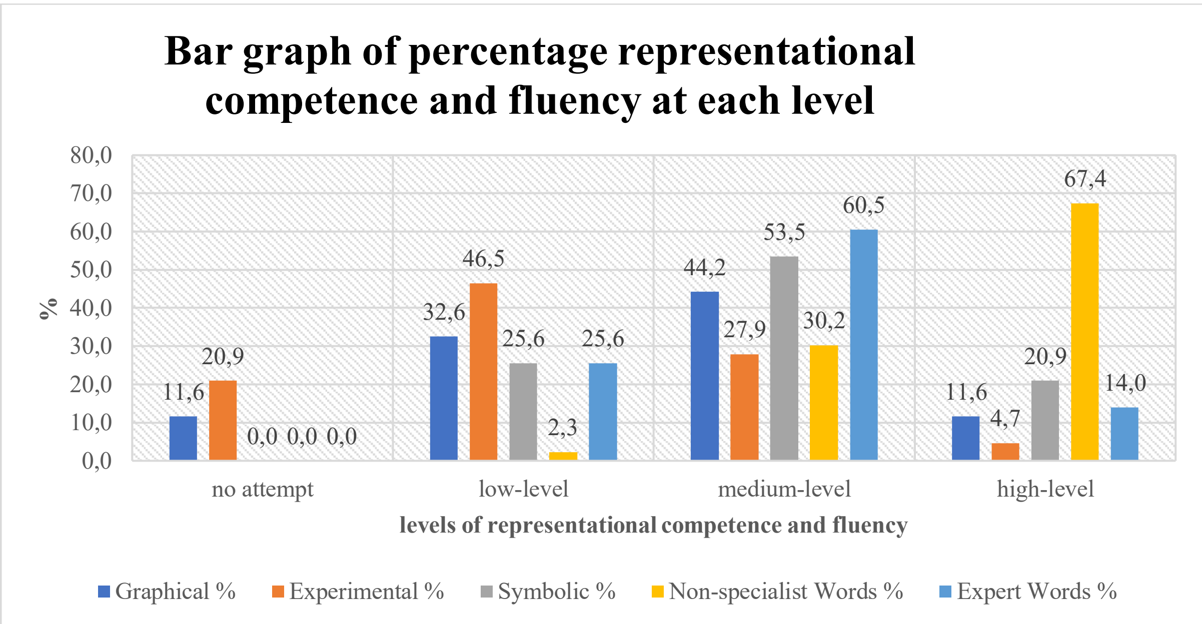


Figure 4.4: Bar graph of percentage representational competence and fluency for pre-service science teachers in Group D

4.2.5 GROUP E VIDEO RECORDINGS: PHYSICS (n=9)

Group E consisted out of 9 participants who had to present a lesson on a topic that is categorised as part of the Physics section in the CAPS curriculum. Out of these 9 participants, 8 participants were part of a group of fourth (and final) year undergraduate PSSTs and 1 participant was part of a group of first (and final) year postgraduate PSSTs at Stellenbosch University which means they should, after having finished the current year of studies, qualify as professional teachers of science.

During the initial coding of the video recorded lessons the following results were obtained for Group E participants:

Table 4.5: Percentage representational competence and fluency at each level for pre-service science teachers in Group E

Level	Graphical %	Experimental %	Symbolic %	Non-specialist Words %	Expert Words %
no attempt	0,0	11,1	66,7	0,0	0,0
low-level	22,2	22,2	0,0	0,0	22,2
medium-level	77,8	22,2	11,1	44,4	44,4
high-level	0,0	44,4	22,2	55,6	33,3

The data can also be presented in the form of a bar graph as to visually represent how the different representational modes and their respective levels of competence and fluency compare for Group E participants:

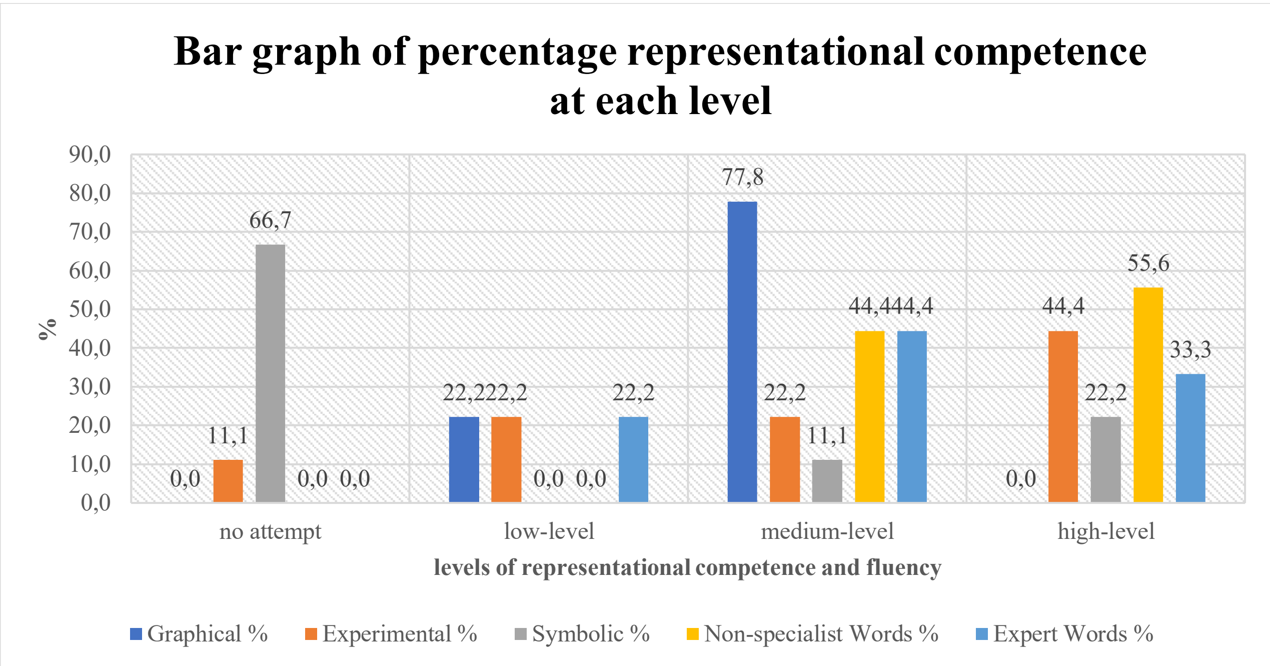


Figure 4.5: Bar graph of percentage representational competence and fluency for pre-service science teachers in Group E

4.2.6 GROUP F VIDEO RECORDINGS: CHEMISTRY (n=3)

Group F consisted out of 3 participants who had to present a lesson on a topic that is categorised as part of the Chemistry section in the CAPS curriculum. Out of these 3 participants, 1 participant was part of a group of fourth (and final) year undergraduate PSSTs and 2 participants were part of a group of first (and final) year postgraduate PSSTs at Stellenbosch University which means they should, after having finished the current year of studies, qualify as professional teachers of science.

During the initial coding of the video recorded lessons the following results were obtained for Group F participants:

Table 4.6: Percentage representational competence and fluency at each level for pre-service science teachers in Group F

Level	Graphical %	Experimental %	Symbolic %	Non-specialist Words %	Expert Words %
no attempt	0,0	100,0	33,3	0,0	0,0
low-level	33,3	0,0	0,0	0,0	33,3
medium-level	0,0	0,0	0,0	33,3	33,3
high-level	66,7	0,0	66,7	66,7	33,3

The data can also be presented in the form of a bar graph as to visually represent how the different representational modes and their respective levels of competence and fluency compare for Group F participants:

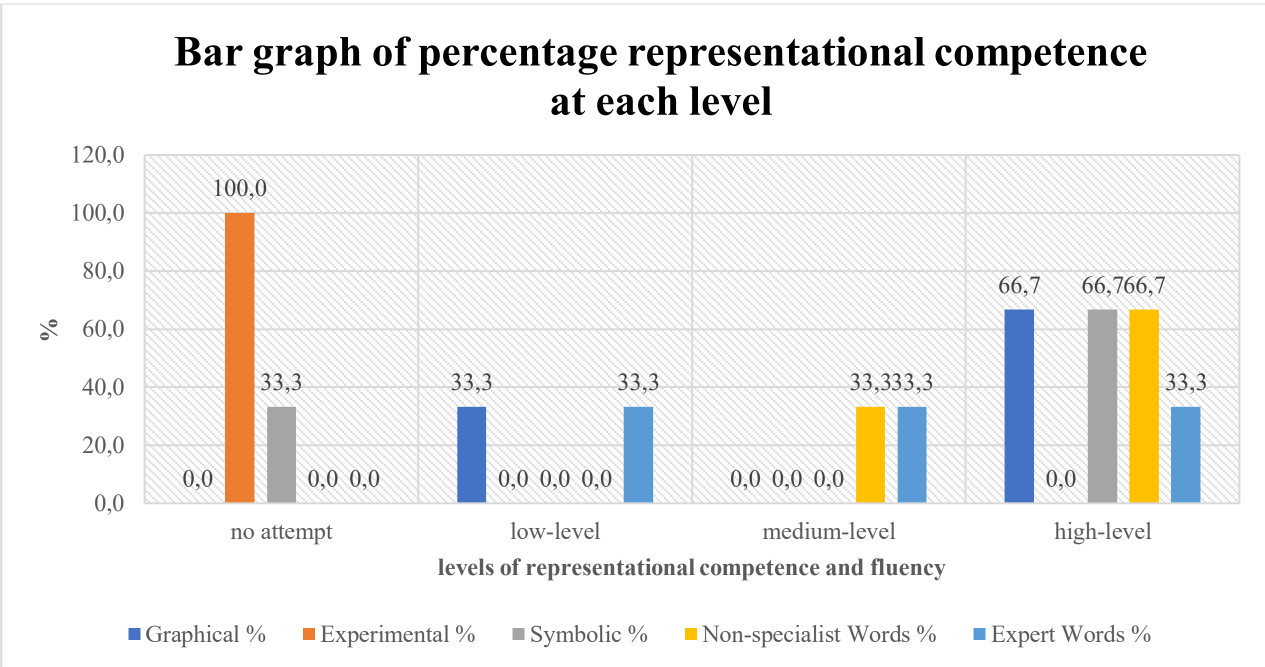


Figure 4.6: Bar graph of percentage representational competence and fluency for pre-service science teachers in Group F

The discussion of the initial coding results was done in Chapter 5, Section 5.2. In the next few sections of this chapter the data obtained after the initial coding phase was used and analysed either qualitatively or quantitatively as to allow me to interpret the data in various ways to potentially answer the research sub-questions and subsequently the main research question the study aimed to answer. Refer to the flow diagram in Figure 1.2 for an overview of the data analyses process. The analysed data in the following sections will be discussed in Chapter 5.

4.3 Different Modes of Representation Used Explicitly

This section aims to analyse and arrange the data in an attempt to answer the following research sub-question in Section 5.3, Chapter 5:

a) What are the different modes of representation that pre-service science teachers explicitly use during lessons?

Explicitly used representational modes would be those modes that evidence could be found during the initial coding of the data. To gather a complete overview of the modes explicitly used, I decided to first look at the evidence found for the Physics lessons, secondly at the evidence found for the Chemistry lessons and thereafter look at all of the evidence obtained as a collective as to get a general overview of the representational modes used in the subjects Natural Sciences or Physical Sciences (not distinguishing between the two) by PSSTs. I did not look at the representational competence or fluency levels for the purpose of this section and approached the initial coded results in such a way that only Level 1, 2 and 3 codes were deemed as evidence for representational modes used explicitly. Thus, Level 0 (zero) codes were ignored and the Level 1, 2 and 3 codes were combined for each representational mode in Physics, Chemistry and Physics and Chemistry combined as indicated in the rest of this section.

4.3.1 Different Modes of Representation Used in Physics

In order for me to answer the question at hand all the coding results obtained for Groups A, B and E was combined and looked at and thus analysed as a collective. In Table 4.7 all the data for the different levels of competence and fluency of all the Physics lessons were combined in a frequency table. Low-level, medium-level and high-level use of a representational mode was seen as evidence of using a specific mode of representation and these were tallied. This amount was then expressed as a percentage of the lessons that provided evidence for a mode used out of the total number of Physics lessons (n=83) analysed for this study.

Table 4.7: Different modes of representation that pre-service science teachers explicitly use during lessons in Physics

Level	Graphical	Experimental	Symbolic	Non-specialist Words	Expert Words
no attempt	7	21	70	2	7
low-level	15	20	5	11	37
medium-level	33	31	4	28	27
high-level	28	11	4	42	12
evidence of a representational mode	76	62	13	81	76
total lessons analysed	83	83	83	83	83
percentage of lessons that have evidence of respective representational mode (%)	91,57	74,70	15,66	97,59	91,57

4.3.2 Different Modes of Representation Used in Chemistry

In order for me to answer the question at hand all the coding results obtained for Groups C, D and F was combined and looked at and thus analysed as a collective. In Table 4.8 all the data for the different levels of competence and fluency of all the Chemistry lessons were combined in a frequency table. Low-level, medium-level and high-level use of a representational mode was seen as evidence of using a specific mode of representation and these were tallied. This amount was then expressed as a percentage of the lessons that provided evidence for a mode used out of the total number of Chemistry lessons (n=84) analysed for this study.

Table 4.8: Different modes of representation that pre-service science teachers explicitly use during lessons in Chemistry

Level	Graphical	Experimental	Symbolic	Non-specialist Words	Expert Words
no attempt	35	12	37	0	9
low-level	16	28	12	8	25
medium-level	26	29	24	31	41
high-level	7	15	11	45	9
evidence of a representational mode	49	72	47	84	75
total lessons analysed	84	84	84	84	84
percentage of lessons that have evidence of respective representational mode (%)	58,33	85,71	55,95	100,00	89,29

4.3.3 Different Modes of Representation Used in Physics and Chemistry Combined

In order for me to answer the question at hand all the coding results obtained for Groups A, B, C, D, E and F was combined and looked at and thus analysed as a collective. In Table 4.9 all the data for the different levels of competence and fluency of all the lessons (Physics and Chemistry) analysed for this study were combined in a frequency table. Low-level, medium-level and high-level use of a representational mode was seen as evidence of using a specific mode of representation and these were tallied. This amount was then expressed as a percentage of the lessons that provided evidence for a mode used out of the total number of lessons (n=167) analysed for this study.

Table 4.9: Different modes of representation that pre-service science teachers explicitly use during lessons in Physics and Chemistry combined

Level	Graphical	Experimental	Symbolic	Non-specialist Words	Expert Words
no attempt	42	33	107	2	16
low-level	31	48	17	19	62
medium-level	59	60	28	59	68
high-level	35	26	15	87	21
evidence of a representational mode	125	134	60	165	151
total lessons analysed	167	167	167	167	167
percentage of lessons that have evidence of respective representational mode (%)	74,85	80,24	35,93	98,80	90,42

The discussion of the results obtained in this section is presented in Chapter 5, Section 5.3.

4.4 Representational Modes Used in Chemistry and Physics

This section aims to analyse and arrange the data in an attempt to answer the following research sub-question in Section 5.4, Chapter 5:

b) Is there a statistically significant difference between pre-service science teachers' use of multiple representations as well as their level of representational competence and fluency in Physics and Chemistry?

The Chi-Square Test was used to determine any statistically significant difference between representational competence in Physics and Chemistry. The same analysis was completed for each one of the Representational Modes (Graphical; Experimental; Symbolic; Non-specialist Words; Expert Words). The analysis was conducted for the whole population of the study where Physics lessons (n=83) and Chemistry lessons (n=84) were grouped.

Jim Frost (2017) explains that the chi-square test of independence may be used when a researcher wants to compare expected - and observed data distributions for different categories, assuming a null-hypothesis. The null-hypothesis states that there is no difference between the expected and observed frequencies. If the chi-square value obtained from the analysis is greater than or equal to 7.815

($p \leq 0.05$) for a data set with 3 degrees of freedom (d=3) a statistically significant chi-square value is obtained and the null-hypothesis is rejected by the data distribution – thus an alternative hypothesis is accepted. The alternative hypothesis states that there is a statistically significant difference between the observed - and the expected results and there must be another influencing factor on the results (Frost, 2017). Should the chi-square value be smaller than 7.815 ($p \geq 0.05$) then it is not statistically significant and the null-hypothesis is accepted. This points towards expected – and observed results that have no association between them (ibid.). Pietersen and Maree (2016) identifies the chi-square test as an applicable analysis to examine whether there is an association between two nominal variables. In this section the two nominal variables (Physics and Chemistry) have 5 categories namely Graphical, Experimental, Symbolic, Non-Specialist Words and Expert words (with no intrinsic or natural ordering).

In order for me to interpret the data and attempt to answer the research sub-question at hand the data was analysed in two parts by means of a chi-square test. First the test was conducted for the modes used, where after the test was conducted for the different levels at which these representational modes were used. The data was set up in a two-way contingency table for the analysis and the chi-square value was obtained. After the chi-square value was obtained the probability value (p) was calculated and these two values were interpreted in terms of their statistical significance, whether the null hypothesis was accepted or rejected and ultimately if the observed - and expected results are significantly statistically different or not. The results obtained for each one of the statistical analyses was represented in two ways, first in the form of a bar graph to show the percentage of the data containing evidence for the different levels of competence and fluency while comparing Physics and Chemistry, and secondly in the form of a table which shows the contribution of each level of competence and fluency to the chi-square value. The results are tabulated below.

4.4.1 Modes of Representation Used in Physics and Chemistry

In order for me to answer the question at hand all the coding results obtained for Groups A, B, and E as well as C, D and F were combined and looked at and thus analysed as a collective of Physics and Chemistry. The table below shows a summary of the chi-square values and statistical interpretations thereof obtained for each one of the representational modes when comparing these for Physics and Chemistry.

Table 4.10: Chi-Square Values for Physics (n=83) vs Chemistry (n=84) for whole population.

Representational Mode	Chi-Square Value	Probability value	Statistical Significance	Is the null-hypothesis accepted? (Is there a statistical difference between the observed and the expected results?)
Graphical	32,12	p=0.00	Yes	No (there is a statistically significant difference)
Experimental	4,46	p=0.22	No	Yes (there is no statistical difference)
Symbolic	30,61	p=0.00	Yes	No (there is a statistically significant difference)
Non-specialist	2,72	p=0.44	No	Yes (there is no statistical difference)
Expert Words	5,88	p=0.12	No	Yes (there is no statistical difference)

Each one of the representational modes' results are presented below by means of a bar graph and a table containing its chi-square calculation values.

GRAPHICAL REPRESENTATIONS

The bar graph below shows the percentage of the data containing evidence for the different levels of competence and fluency for Graphical Representations while comparing Physics and Chemistry. These percentages were calculated from the results obtained during the initial coding of the video recorded lessons.

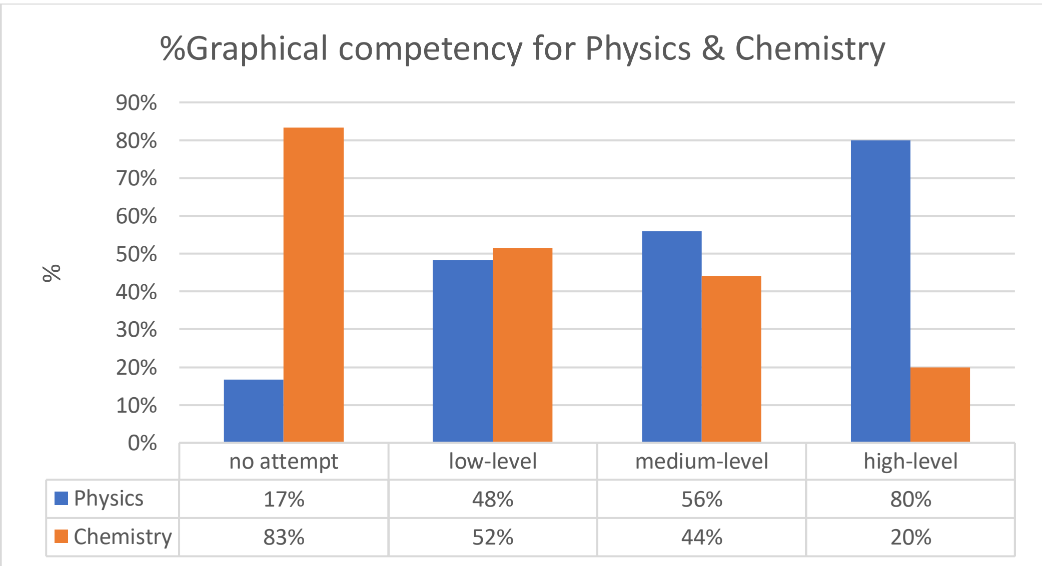


Figure 4.7: Bar graph of percentage Graphical representational competence and fluency for pre-service science teachers

The calculations and values in the table below were used to determine the chi-square value for the different levels of competence and fluency for Graphical Representations while comparing Physics and Chemistry. The values in this table will be used to discuss the contributors to the observed – and expected results being found statistically different, if relevant.

Table 4.11: Chi-Square Value Calculation for Physics (n=83) vs Chemistry (n=84) for whole population's Graphical Competence and Fluency

Level of Competence and Fluency	OBSERVED (O)		EXPECTED (E)		(O-E)^2/E		
	Physics	Chemistry	Physics	Chemistry	Physics	Chemistry	
no attempt	7	35	20,87	21,13	9,22	9,11	
low-level	15	16	15,41	15,59	0,01	0,01	
medium-level	33	26	29,32	29,68	0,46	0,46	
high-level	28	7	17,40	17,60	6,47	6,39	χ^2
				TOTAL	16,16	15,97	**32,12**

EXPERIMENTAL REPRESENTATIONS

The bar graph below shows the percentage of the data containing evidence for the different levels of competence and fluency for Experimental Representations while comparing Physics and Chemistry. These percentages were calculated from the results obtained during the initial coding of the video recorded lessons.

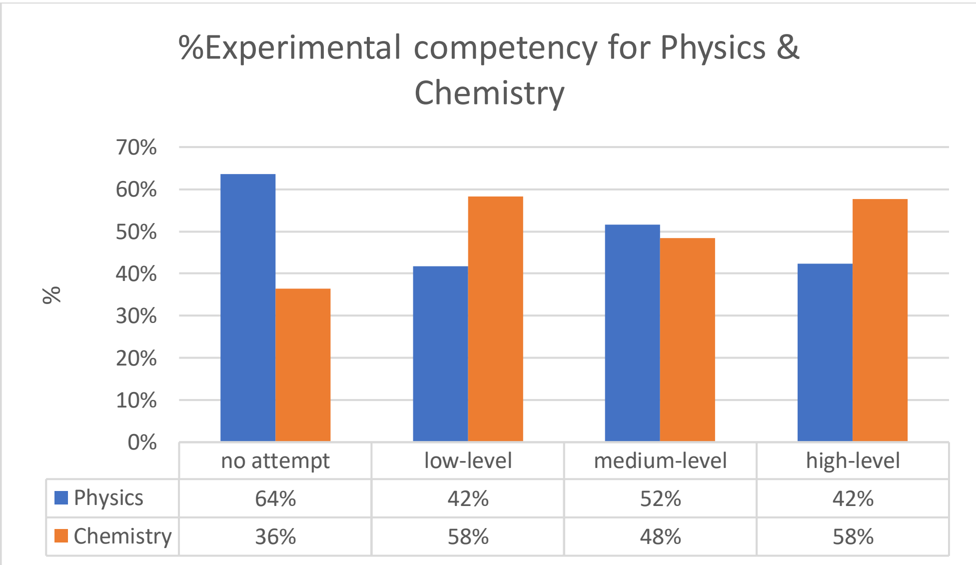


Figure 4.8: Bar graph of percentage Experimental representational competence and fluency for pre-service science teachers

The calculations and values in the table below were used to determine the chi-square value for the different levels of competence and fluency for Experimental Representations while comparing Physics and Chemistry. The values in this table will be used to discuss the contributors to the observed – and expected results being found statistically different, if relevant.

Table 4.12: Chi-Square Value Calculation for Physics (n=83) vs Chemistry (n=84) for whole population's Experimental Competence and Fluency

Level of Competence and Fluency	OBSERVED (O)		EXPECTED (E)		(O-E)^2/E		
	Physics	Chemistry	Physics	Chemistry	Physics	Chemistry	
no attempt	21	12	16,40	16,60	1,29	1,27	
low-level	20	28	23,86	24,14	0,62	0,62	
medium-level	31	29	29,82	30,18	0,05	0,05	
high-level	11	15	12,92	13,08	0,29	0,28	χ^2
				TOTAL	2,25	2,22	**4,46**

SYMBOLIC REPRESENTATIONS

The bar graph below shows the percentage of the data containing evidence for the different levels of competence and fluency for Symbolic Representations while comparing Physics and Chemistry. These percentages were calculated from the results obtained during the initial coding of the video recorded lessons.

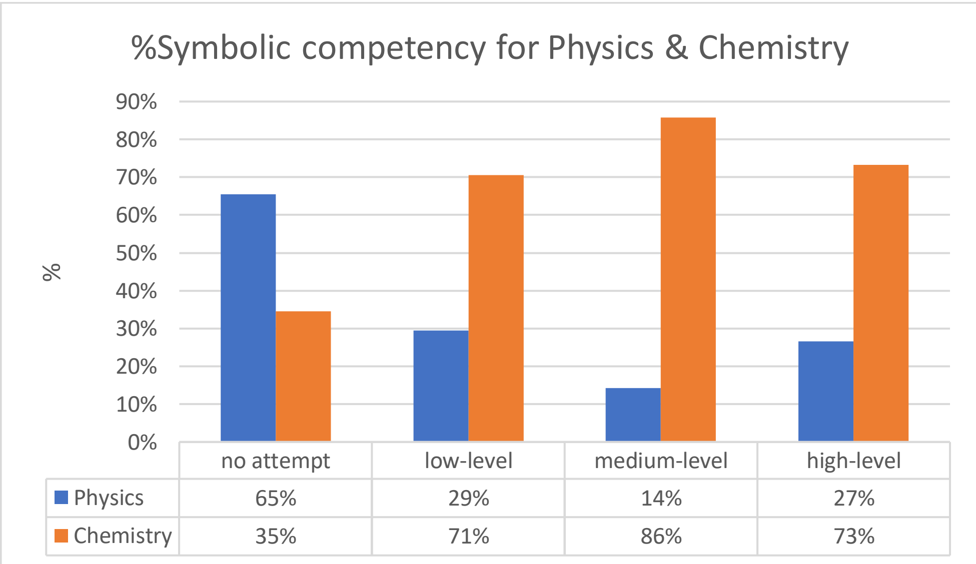


Figure 4.9: Bar graph of percentage Symbolic representational competence and fluency for pre-service science teachers

The calculations and values in the table below were used to determine the chi-square value for the different levels of competence and fluency for Symbolic Representations while comparing Physics and Chemistry. The values in this table will be used to discuss the contributors to the observed – and expected results being found statistically different, if relevant.

Table 4.13: Chi-Square Value Calculation for Physics (n=83) vs Chemistry (n=84) for whole population's Symbolic Competence and Fluency

Level of Competence and Fluency	OBSERVED (O)		EXPECTED (E)		(O-E)^2/E		
	Physics	Chemistry	Physics	Chemistry	Physics	Chemistry	
no attempt	70	37	53,18	53,82	5,32	5,26	
low-level	5	12	8,45	8,55	1,41	1,39	
medium-level	4	24	13,92	14,08	7,07	6,98	
high-level	4	11	7,46	7,54	1,60	1,58	χ^2
				TOTAL	15,40	15,21	30,61

NON-SPECIALIST WORDS

The bar graph below shows the percentage of the data containing evidence for the different levels of competence and fluency for Non-specialist Words while comparing Physics and Chemistry. These percentages were calculated from the results obtained during the initial coding of the video recorded lessons.

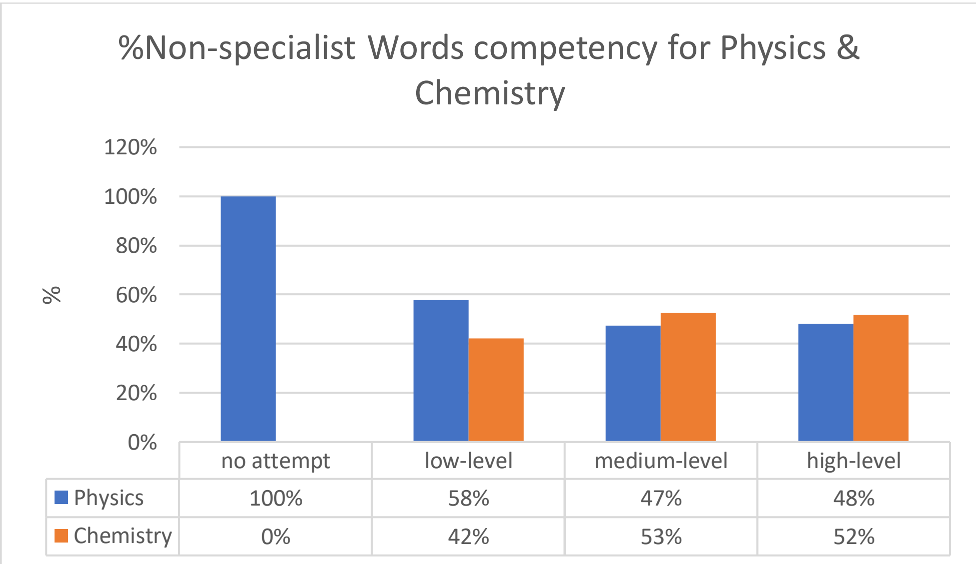


Figure 4.10: Bar graph of percentage Non-specialist Words representational competence and fluency for pre-service science teachers

The calculations and values in the table below were used to determine the chi-square value for the different levels of competence and fluency for Non-specialist Words while comparing Physics and Chemistry. The values in this table will be used to discuss the contributors to the observed – and expected results being found statistically different, if relevant.

Table 4.14: Chi-Square Value Calculation for Physics (n=83) vs Chemistry (n=84) for whole population's Non-specialist Words Competence and Fluency

Level of Competence and Fluency	OBSERVED (O)		EXPECTED (E)		(O-E)^2/E		
	Physics	Chemistry	Physics	Chemistry	Physics	Chemistry	
no attempt	2	0	0,99	1,01	1,02	1,01	
low-level	11	8	9,44	9,56	0,26	0,25	
medium-level	28	31	29,32	29,68	0,06	0,06	
high-level	42	45	43,24	43,76	0,04	0,04	χ^2
				TOTAL	1,37	1,35	**2,72**

EXPERT WORDS

The bar graph below shows the percentage of the data containing evidence for the different levels of competence and fluency for Expert Words while comparing Physics and Chemistry. These percentages were calculated from the results obtained during the initial coding of the video recorded lessons.

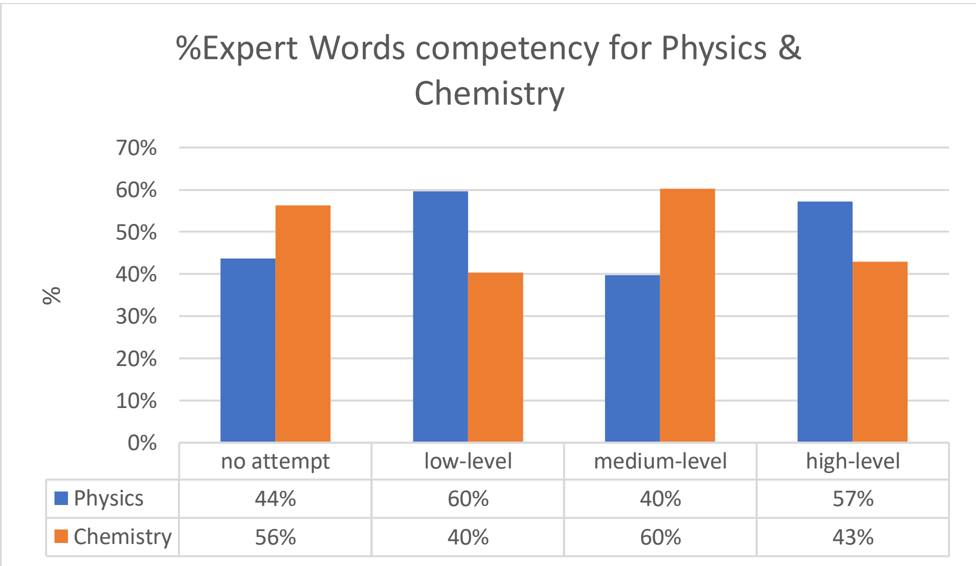


Figure 4.11: Bar graph of percentage Expert Words representational competence and fluency for pre-service science teachers

The calculations and values in the table below were used to determine the chi-square value for the different levels of competence and fluency for Expert Words while comparing Physics and Chemistry. The values in this table will be used to discuss the contributors to the observed – and expected results being found statistically different, if relevant.

Table 4.15: Chi-Square Value Calculation for Physics (n=83) vs Chemistry (n=84) for whole population's Expert Words Competence and Fluency

Level of Competence and Fluency	OBSERVED (O)		EXPECTED (E)		(O-E)^2/E		
	Physics	Chemistry	Physics	Chemistry	Physics	Chemistry	
no attempt	7	9	7,95	8,05	0,11	0,11	
low-level	37	25	30,81	31,19	1,24	1,23	
medium-level	27	41	33,80	34,20	1,37	1,35	
high-level	12	9	10,44	10,56	0,23	0,23	χ^2
				TOTAL	2,96	2,92	5,88

In this section (4.4.1) the analysis was completed for each one of the representational modes to determine if the observed and expected results of representational competence and fluency of PSSTs was statistically different for Physics and Chemistry. In the next section (4.4.2) all of the representational modes' results were combined into the four different levels of competence and fluency for Physics and Chemistry respectively and analysed as such.

4.4.2 Levels of Competence and Fluency Modes of Representation Was Used in Physics and Chemistry

In order for me to answer the question at hand all the coding results obtained for Groups A, B, and E as well as C, D and F were combined and looked at and thus analysed as a collective of Physics and Chemistry. In this section the analysis was completed for each one of the levels of competence and fluency to determine if the observed and expected results were statistically different for Physics and Chemistry. The results will thus be interpreted in terms of the levels of competence and fluency for Physics and Chemistry, irrespective of the representational mode used.

In the table below the frequency of occurrence of each of the levels of competence and fluency obtained during the initial coding of the video recorded lessons was indicated. These values were obtained by adding the frequencies of occurrence of each of the levels for the different representational modes together for Physics and Chemistry.

Table 4.16: Physics (n=83) vs Chemistry (n=84) for whole population on different levels

	Sum of Levels for Physics and Chemistry across all representational modes	
Levels	Physics	Chemistry
no attempt	107	93
low-level	88	89
medium-level	123	151
high-level	97	87

The table below shows a summary of the chi-square value and statistical interpretation thereof obtained when comparing the levels of competence and fluency for Physics and Chemistry.

Table 4.17: Chi-Square Values for Physics (N=83) vs Chemistry (N=84) for whole population on different levels

	Chi-Square Value	Probability value	Statistical Significance	Is the null-hypothesis accepted? Is there a statistically significant difference between the observed and the expected results?
Level of Competence and Fluency in Chemistry and Physics	4,36	p=0.23	No	Yes (there is no statistically significant difference)

The bar graph below shows the percentage of the data containing evidence for the different levels of competence and fluency for all the representational modes combined while comparing Physics and Chemistry. These percentages were calculated from the results obtained during the initial coding of the video recorded lessons.

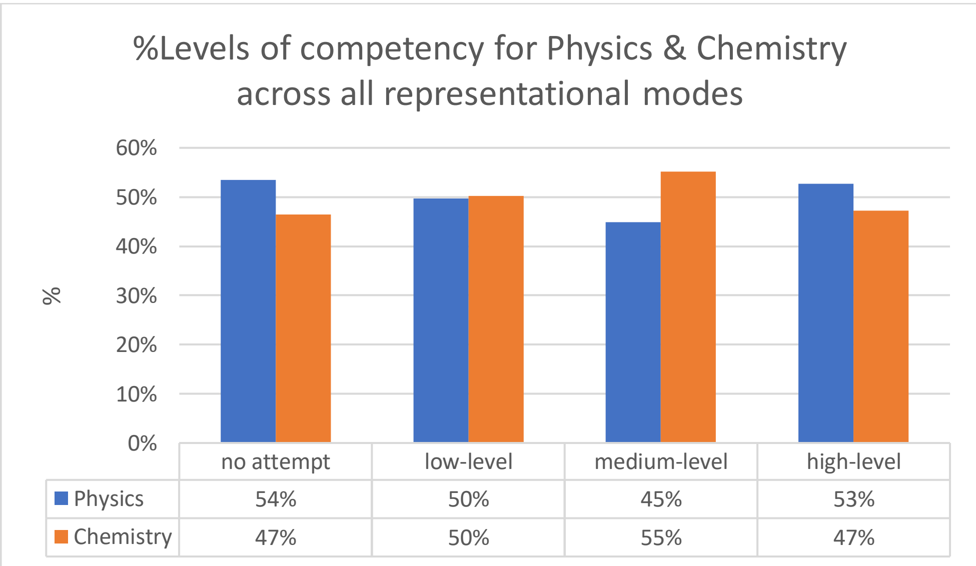


Figure 4.12: Bar graph of percentage representational competence and fluency for pre-service science teachers for Physics and Chemistry across all representational modes

The calculations and values in the table below were used to determine the chi-square value for the different levels of competence and fluency for all the representational modes combined while comparing Physics and Chemistry. The values in this table will be used to discuss the contributors to the observed – and expected results being found statistically different, if relevant.

Table 4.18: Chi-Square Value Calculation for Physics (n=83) vs Chemistry (n=84) for whole population's Competence and Fluency levels across all representational modes

Level of Competence and Fluency	OBSERVED (O)		EXPECTED (E)		(O-E)^2/E		
	Physics	Chemistry	Physics	Chemistry	Physics	Chemistry	
no attempt	107	93	99,40	100,60	0,58	0,57	
low-level	88	89	87,97	89,03	0,00	0,00	
medium-level	123	151	136,18	137,82	1,28	1,26	
high-level	97	87	91,45	92,55	0,34	0,33	χ^2
				TOTAL	2,19	2,17	**4,36**

The discussion of the results obtained in this section is presented in Chapter 5, Section 5.4.

4.5 Integration across Different Modes of Representation

This section aims to analyse and arrange the data in an attempt to answer the following research sub-question in Section 5.5, Chapter 5:

c) How do pre-service science teachers engage in translation activities (integration across different modes of representation) in order to explain a specific scientific concept?

A Secondary coding was conducted on the results of the initial coding in an attempt to investigate the fluency between different representational modes for Physics and Chemistry respectively. The codes assigned in this step was for the different modes of representation as indicated in Table 3.4 (Chapter 3).

First, these codes where assigned to the representations in the lessons where a Level 3 code was obtained in the initial coding phase. Thereafter, where these (secondary) codes were assigned for Level 3 codes, the coding was repeated for the representations where a Level 2 code was obtained. Thus, if no Level 3 code was obtained for a lesson, no Level 2 code went through a secondary coding phase for that specific lesson. Results for the secondary coding was discarded (ignored) if:

- A Level 3 code was obtained, but no Level 2 code, and there were less than 3 secondary codes assigned
- A Level 3 and Level 2 code was obtained but in total less than 3 secondary codes were assigned

Results for the secondary coding qualified (used for the results interpretation and seen as being indicative of fluency between representational modes) if:

- A Level 3 code was obtained and 3 or more secondary codes were assigned

- A Level 3 and Level 2 code was obtained and in total 3 or more secondary codes were assigned

For those lessons that qualified the secondary codes were combined in the order G, E, S, NS, X if present (Addendum M). The different code combinations were identified and tallied for Physics and Chemistry and expressed as a frequency of occurrence (Tables 4.19 and 4.20).

4.5.1 Integration across Different Modes of Representation in Physics

In order for me to answer the question at hand all the coding results obtained for Groups A, B and E were combined and looked at and thus analysed as a collective. The table below shows that a total of 43 codes qualified out of the 83 lessons analysed and, when combined, 7 different code combinations occurred.

Table 4.19: Representational mode coding combinations obtained for Physics (n=83) indicative of fluency between the modes.

Codes Obtained for Physics	Times a specific code was obtained in Physics
GENS	9
GENSX	11
ENSX	2
GESNSX	4
GSNSX	3
GNSX	13
GSNS	1
Total codes	*43*

4.5.2 Integration across Different Modes of Representation in Chemistry

In order for me to answer the question at hand all the coding results obtained for Groups C, D and F was combined and looked at and thus analysed as a collective. The table below shows that a total of 44 codes qualified out of the 84 lessons analysed and, when combined, 7 different code combinations occurred.

Table 4.20: Representational mode coding combinations obtained for Chemistry (n=84) indicative of fluency between the modes.

Codes Obtained for Chemistry	Times a specific code was obtained in Chemistry
GENSX	5
ENSX	8
GESNSX	5
GSNSX	14
GSNS	2
ESNSX	3
SNSX	7
Total codes	*44*

The discussion of the results obtained in this section takes place in Chapter 5, Section 5.5. The three code combinations with the highest frequency of occurrence in both the Physics and Chemistry data was identified and elaborated on in the discussion of the results.

4.6 The Use of Everyday Literacy vs Scientific Literacy

This section aims to analyse and arrange the data in an attempt to answer the following research sub-question in Section 5.6, Chapter 5:

d) Is there a statistically significant difference in how pre-service science teachers use every day literacy compared to scientific literacy?

The Chi-Square Test was used to determine any statistically significant difference between representational competence in the use of Non-specialist Words and Expert Words representational modes. The same analysis was completed for Physics (n=83), Chemistry (n=84) and Physics and Chemistry combined (n=167). To gather a complete overview of the Non-specialist Words and the Expert Words used I decided to first look at the evidence found for the Physics lessons (Groups A, B and E combined), secondly at the evidence found for the Chemistry lessons (Group C, D and E combined) and thereafter look at all of the evidence obtained as a collective (Groups A, B. C. D. E and F combined) as to get a general overview of these representational modes used in the subjects Natural Sciences or Physical Sciences (not distinguishing between the two) by PSSTs.

The interpretation of the results was done in a similar fashion as set out in Section 4.4. The data was set up in a two-way contingency table for the analysis and the chi-square value was obtained. After the chi-square value was obtained the probability value (p) was calculated and these two values were interpreted in terms of their statistical significance, whether the null hypothesis was accepted or rejected and ultimately if the observed - and expected results are significantly statistically different or not. The results obtained for each one of the statistical analyses was represented in two ways, first in the form of a bar graph to show the percentage of the data containing evidence for the different levels of competence and fluency while comparing the use of Non-Specialist Words and Expert Words, and secondly in the form of a table which shows the contribution of each level of competence and fluency to the chi-square value. The table below shows a summary of the chi-square values and statistical interpretations thereof obtained for each one of the representational modes when comparing these for Physics, Chemistry and Physics and Chemistry combined.

Table 4.21: Chi-Square Values for Non-Specialist Words vs Expert Words in Physics, Chemistry and Physics and Chemistry Combined

	Chi-Square Value	Probability value	Statistical Significance	Is the null-hypothesis accepted? (Is there a statistically significant difference between the observed and the expected results?)
Non-specialist Words and Expert Words in Physics	33,55	$p < 0.05$	Yes	No (there is a statistically significant difference)
Non-specialist Words and Expert Words in Chemistry	43,15	$p < 0.05$	Yes	No (there is a statistically significant difference)
Non-specialist Words and Expert Words in Physics and Chemistry combined	74,69	$p < 0.05$	Yes	No (there is a statistically significant difference)

The results are presented below for Physics, Chemistry and Physics and Chemistry combined by means of a bar graph and a table containing its chi-square calculation values.

4.6.1 The Use of Everyday Literacy vs Scientific Literacy in Physics

In order for me to answer the question at hand all the coding results obtained for Groups A, B and E was combined and looked at and thus analysed as a collective. The bar graph below shows the percentage of the data containing evidence for the different levels of competence and fluency for Non-specialist Words compared to Expert Words for Physics. These percentages were calculated from the results obtained during the initial coding of the video recorded lessons.

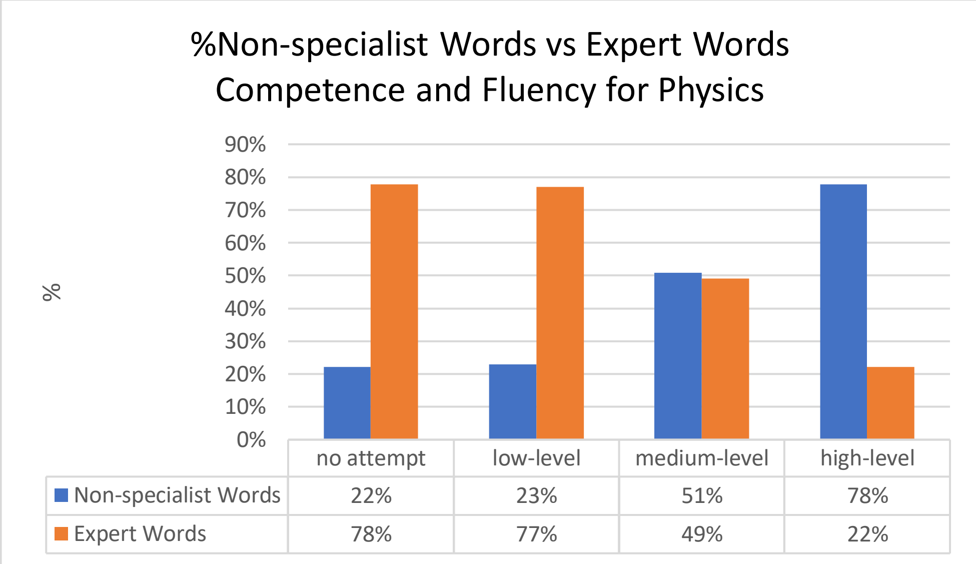


Figure 4.13: Bar graph of percentage Non-specialist Words vs Expert Words representational competence and fluency for pre-service science teachers in Physics

The calculations and values in the table below were used to determine the chi-square value for the different levels of competence and fluency for Non-specialist Words compared to Expert Words for Physics. The values in this table will be used to discuss the contributors to the observed – and expected results being found statistically different, if relevant.

Table 4.22: Chi-Square Value Calculation of Non-specialist Words vs Expert Words representational competence and fluency in Physics (n=83)

Level of Competence and Fluency	OBSERVED (O)		EXPECTED (E)		(O-E)^2/E		
	Non-specialist Words	Expert Words	Non-specialist Words	Expert Words	Non-specialist Words	Expert Words	
no attempt	2	7	4,50	4,50	1,39	1,39	
low-level	11	37	24,00	24,00	7,04	7,04	
medium-level	28	27	27,50	27,50	0,01	0,01	
high-level	42	12	27,00	27,00	8,33	8,33	χ^2
				TOTAL	16,77	16,77	33,55

In this section (4.6.1) the analysis was completed for each one of the levels of competence and fluency to determine if the observed and expected results of representational competence and fluency of PSSTs was statistically different for Non-specialist Words compared to Expert Words in Physics. In the next section (4.6.2) the four different levels of competence and fluency was analysed comparing Non-specialist Words and Expert Words in Chemistry.

4.6.2 The Use of Everyday Literacy vs Scientific Literacy in Chemistry

In order for me to answer the question at hand all the coding results obtained for Groups C, D and F was combined and looked at and thus analysed as a collective. The bar graph below shows the percentage of the data containing evidence for the different levels of competence and fluency for Non-specialist Words compared to Expert Words for Chemistry. These percentages were calculated from the results obtained during the initial coding of the video recorded lessons.

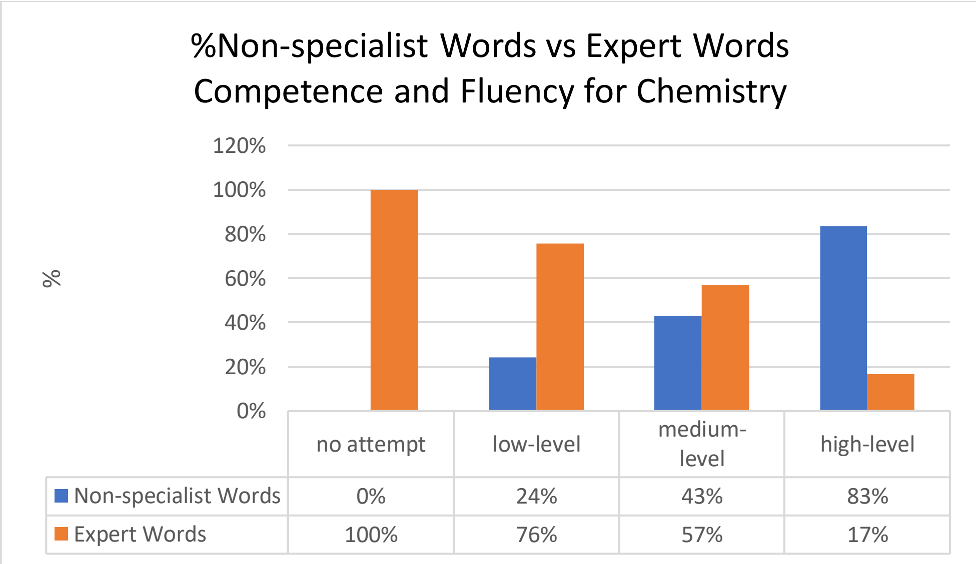


Figure 4.14: Bar graph of percentage Non-specialist Words vs Expert Words representational competence and fluency for pre-service science teachers in Chemistry

The calculations and values in the table below were used to determine the chi-square value for the different levels of competence and fluency for Non-specialist Words compared to Expert Words for Chemistry. The values in this table will be used to discuss the contributors to the observed – and expected results being found statistically different, if relevant.

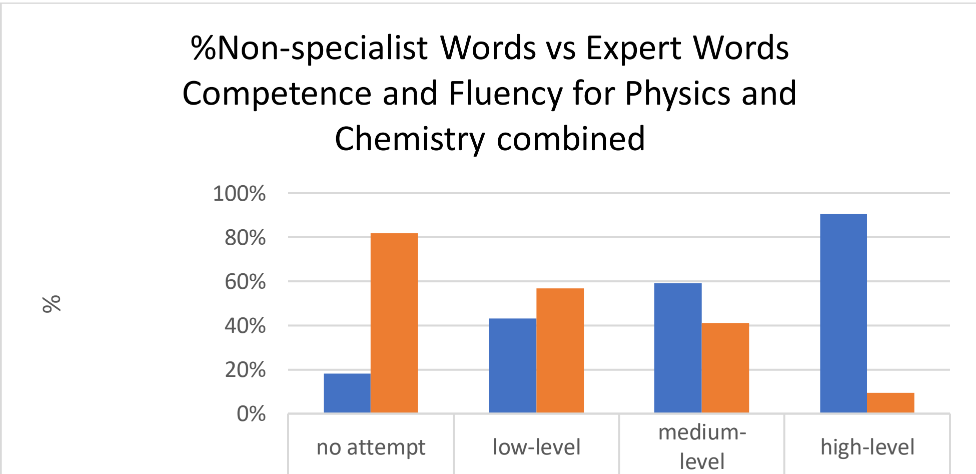
Table 4.23: Chi-Square Value Calculation of Non-specialist Words vs Expert Words representational competence and fluency in Chemistry (n=84)

Level of Competence and Fluency	OBSERVED (O)		EXPECTED (E)		(O-E)^2/E		
	Non-specialist Words	Expert Words	Non-specialist Words	Expert Words	Non-specialist Words	Expert Words	
no attempt	0	9	4,50	4,50	4,50	4,50	
low-level	8	25	16,50	16,50	4,38	4,38	
medium-level	31	41	36,00	36,00	0,69	0,69	
high-level	45	9	27,00	27,00	12,00	12,00	χ^2
				TOTAL	21,57	21,57	**43,15**

In this section (4.6.2) the analysis was completed for each one of the levels of competence and fluency to determine if the observed and expected results of representational competence and fluency of PSSTs was statistically different for Non-specialist Words compared to Expert Words in Chemistry. In the next section (4.6.3) the four different levels of competence and fluency was analysed comparing Non-specialist Words and Expert Words in Physics and Chemistry combined.

4.6.3 The Use of Everyday Literacy vs Scientific Literacy in Physics and Chemistry Combined

In order for me to answer the question at hand all the coding results obtained for Groups A, B, C, D, E and F was combined and looked at and thus analysed as a collective. The bar graph below shows the percentage of the data containing evidence for the different levels of competence and fluency for Non-specialist Words compared to Expert Words for Physics and Chemistry combined. These percentages were calculated from the results obtained during the initial coding of the video recorded lessons.



	no attempt	low-level	medium-level	high-level
Non-specialist Words	18%	43%	59%	91%
Expert Words	82%	57%	41%	9%

Figure 4.15: Bar graph of percentage Non-specialist Words vs Expert Words representational competence and fluency for pre-service science teachers in Physics and Chemistry combined

The calculations and values in the table below were used to determine the chi-square value for the different levels of competence and fluency for Non-specialist Words compared to Expert Words for Physics and Chemistry combined. The values in this table will be used to discuss the contributors to the observed – and expected results being found statistically different, if relevant.

Table 4.24: Chi-Square Value Calculation of Non-specialist Words vs Expert Words representational competence and fluency in Physics and Chemistry combined (n=167)

Level of Competence and Fluency	OBSERVED (O)		EXPECTED (E)		(O-E)^2/E		
	Non-specialist Words	Expert Words	Non-specialist Words	Expert Words	Non-specialist Words	Expert Words	
no attempt	2	16	9,00	9,00	5,44	5,44	
low-level	19	62	40,50	40,50	11,41	11,41	
medium-level	59	68	63,50	63,50	0,32	0,32	
high-level	87	21	54,00	54,00	20,17	20,17	χ^2
				TOTAL	37,34	37,34	**74,69**

In this section (4.6.3) the analysis was completed for each one of the levels of competence and fluency to determine if the observed and expected results of representational competence and fluency of PSSTs was statistically different for Non-specialist Words compared to Expert Words in Physics and Chemistry combined. The discussion of the results obtained in this section takes place in Chapter 5, Section 5.6.

4.7 Conclusion

The analyses and data in this chapter will inform the discussion to follow in the next chapter. In this Chapter initial coding results for each of the different groups were summarised (Section 4.2) and noteworthy observations were pointed out and emphasised by means of descriptive statistics. Thereafter each research sub-question was addressed through Sections 4.3 – 4.6 with appropriate and relevant statistical analyses and qualitative analyses. In the following chapter I will discuss two examples, one Physics and one Chemistry, I identified as lessons presentations which showcases relatively high levels of competence and fluency and why certain codes were assigned, and I will also discuss basic findings and observations made from the initial coded data for the different groups (A-F), giving an example from the data collected, that generally reflects the findings for each group. Next, I will discuss the same four sections as set out in this chapter (Different Modes of Representation Used Explicitly; Representational Modes Used in Chemistry and Physics; Integration across Different Modes of Representation; The Use of Everyday Literacy vs Scientific Literacy) and discuss for each one of these sections by means of the data in this chapter, again using examples.

CHAPTER 5: DISCUSSION OF RESEARCH RESULTS

5.1 Introduction

The data collection methods in this study took place in the form of video recorded lesson presentations. These lessons were coded by means of pre-determined categories and levels as set out in previous chapters. This data was then analysed qualitatively and quantitatively to investigate emerging concepts as to potentially address the pre-determined research sub-questions and to finally discuss the main research question the study aims to answer, namely: "How do pre-service science teachers use multiple representations as a pedagogical tool to explain science concepts during their lessons?". The initial coded data, a secondary coding, visual aspects (such as screenshots etc.) and notes made during coding were used for qualitative analyses purposes and combined as to enrich and strengthen the observations and findings of this study. The initial coded data was also analysed quantitatively by means of descriptive statistics and statistical analyses using the chi-square test to report on some of the findings in this study.

I begin this chapter by discussing two examples, one Physics and one Chemistry, I identified as lessons presentations which showcase relatively high levels of competence and fluency and why certain codes were assigned. The chapter continues after this with the very basic findings and observations made from the initial coded data for the different groups (A-F). The context of each group's data collection setting is then taken into account as to discuss these findings briefly, giving an example from the data collected that generally reflects the findings for each group. This is then followed up by findings from the literature studied as to strengthen or explain some of the findings. Next, I will follow up with the same four sections as set out in Chapter 4 (Different Modes of Representation Used Explicitly; Representational Modes Used in Chemistry and Physics; Integration Across Different Modes of Representation; The Use of Everyday Literacy vs Scientific Literacy) and discuss for each one of these sections the relevant data and findings while using examples from the data collected during the video recorded lesson presentations. The findings will again be aligned with previous studies' findings, where possible. This chapter will then conclude with general observations and findings of the study as a whole.

5.2 Discussion on Observations from Initial Coding Results for Different Groups

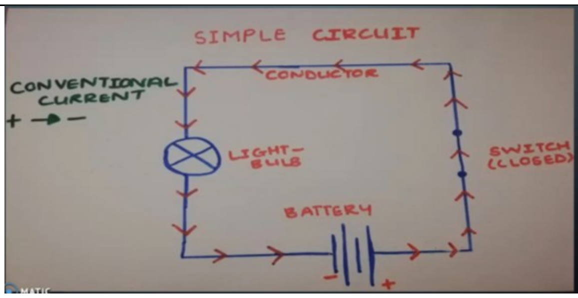
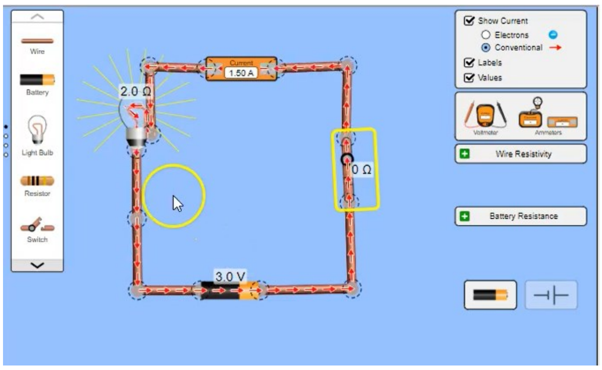
The results in this section was obtained when the video recorded lessons was coded as set out in Chapter 3 and Chapter 4. These results were also used and underwent further analyses to obtain the results in Sections 4.3 – 4.6 in order for me to interpret the data in ways that could potentially shed light on the research sub-questions. In Table 5.1 and Table 5.2 the interpretations of one Physics and one Chemistry lesson can be found. These are examples of lessons with relatively high levels of competence and fluency compared to the other Physics and Chemistry lessons observed and analysed, as well as having used all five representational modes. The competence and fluency is discussed for each one of the representational modes and where necessary the lack of competence or fluency was also pointed out. Thus, these two examples does not necessarily reflect only high-level competence and fluency in the use of MRs by PSSTs, but are examples of some of the highest levels observed during this study. The purpose of this section is to show how I interpreted the levels of competence and fluency when the data was coded during the initial coding phase.

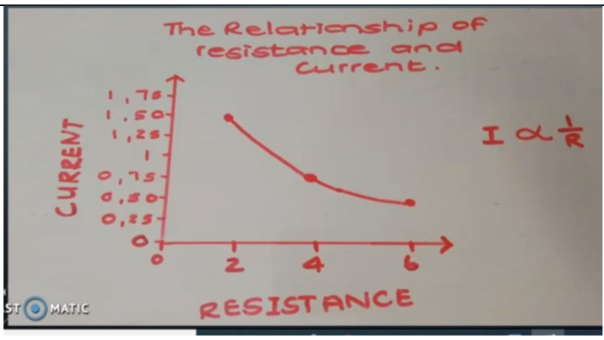
EXAMPLE OF PHYSICS LESSON

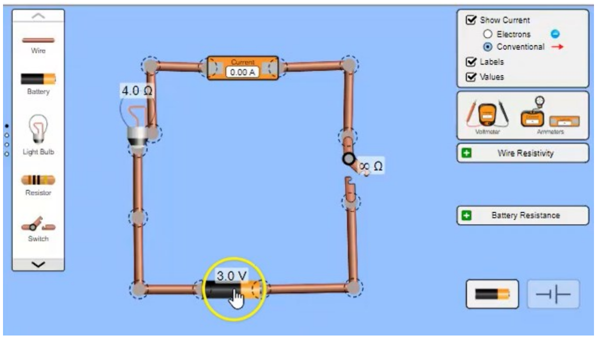
In the table below I focus on and discuss the different representations used in a lesson where the PSST presented on the concept of electrical circuits. The codes obtained for this specific example was as follows:

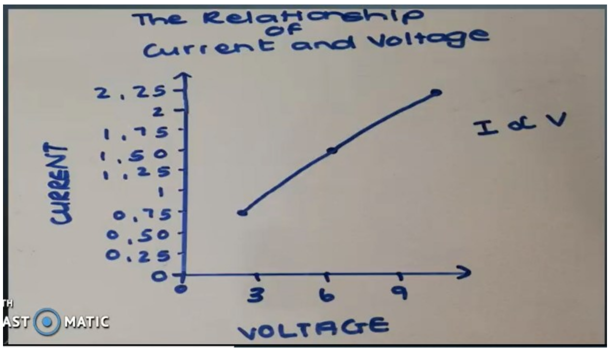
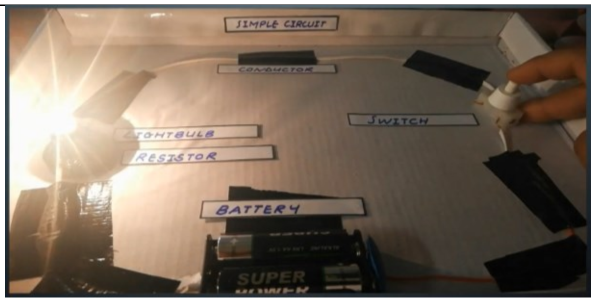
- Code 3 for Graphical Representations
- Code 3 for Experimental Representations
- Code 3 for Symbolic Representations
- Code 3 for Non-specialist Words
- Code 2 for Expert Words

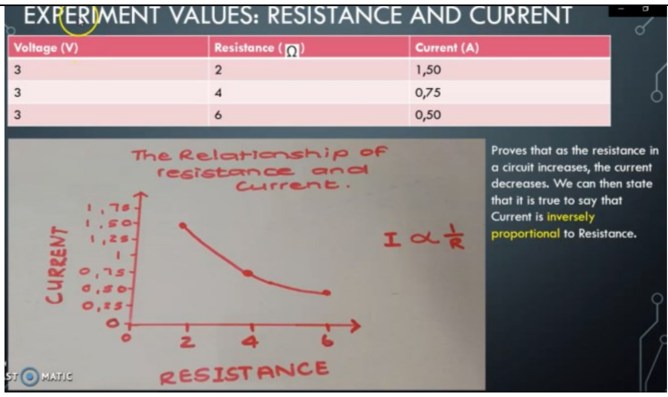
Table 5.1: Example of lesson analysis and coding for a Physics lesson presented at a relatively high level of competence and fluency (Unit 13:GroupA)

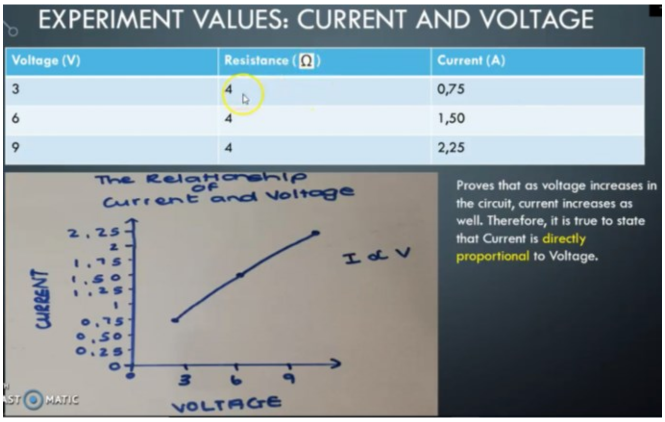
Graphical Representations		
Example	 	5.1a

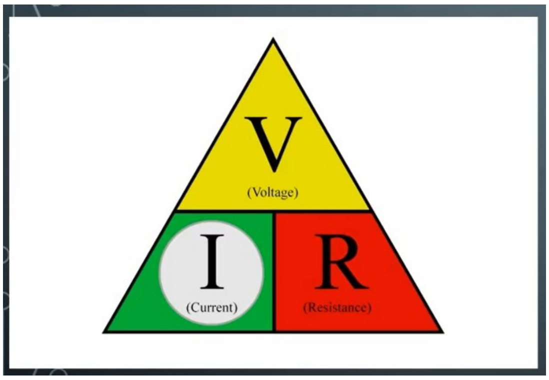
<table>
<tr><td></td><td>

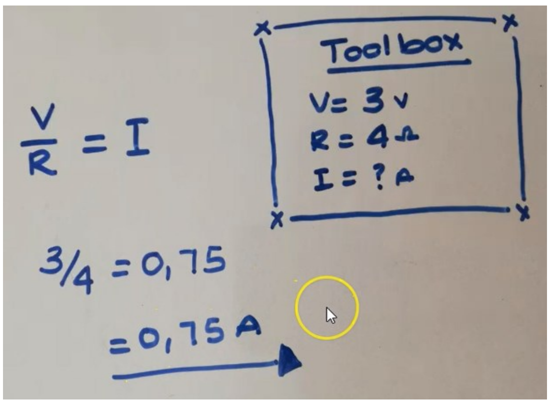



</td><td></td></tr>
<tr><td>Discussion</td><td>The circuit diagram is drawn from the experimental circuit (5.1b) that was built and each symbol is discussed alongside the drawing thereof. The same circuit is then built in the PHET simulator. The simulator is then used to generate data as to accept or reject the hypothesis made (5.1d) based on Ohm's Law. The data generated is used to plot graphs. The data generation process is repeated twice: first the V is kept constant while changing the R and measuring the I; then the R is kept constant while changing the V and measuring the I. The observations made during the data generation are also linked in terms of "how fast the current moves" and "the brightness of the bulb". The results are linked to the symbolic representations (5.1c).</td><td></td></tr>
<tr><td colspan="2">Experimental Representations</td><td></td></tr>
<tr><td>Example</td><td>
</td><td>5.1b</td></tr>
</table>

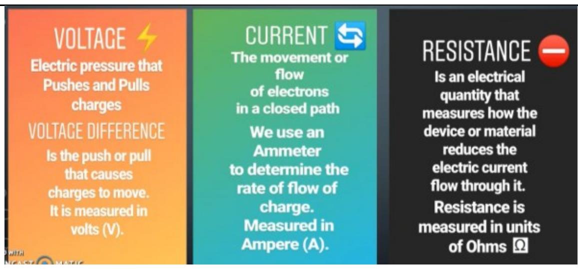
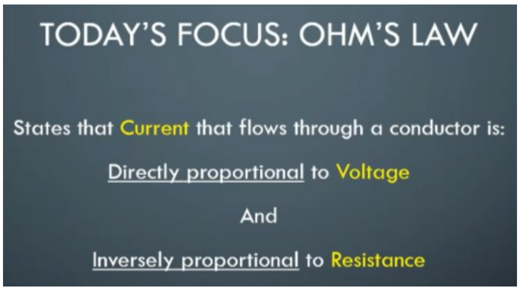
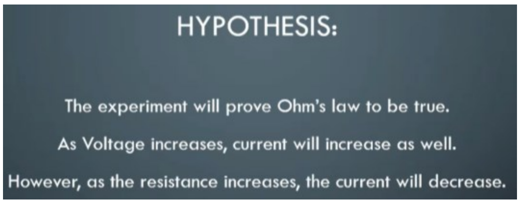
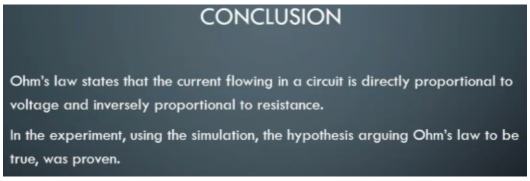
<table>
<tr><td>Discussion</td><td>The participant explains the setup of the simple circuit, mentions that minimum 3 components are needed to build a simple circuit: switch, battery, lightbulb acted as resistor, conductor. Does not mention which 3 out of the 4 components mentioned are the required ones. This experiment is then used to initiate the discussion of the components used in the simulator (5.1a) and the drawing of the circuit diagram.</td><td></td></tr>
<tr><td colspan="2">Symbolic Representations</td><td></td></tr>
<tr><td>Example</td><td>








</td><td>5.1c</td></tr>
</table>

Discussion	Ohm's Law is stated and verified through the data generated by means of the graphical representations (5.1a). The shape of the graphs are interpreted as mathematical relationships, which was then used to represent these relationships symbolically. One set of data is then used to prove the formula for Ohm's Law works.	
Non-specialist Words		
Example	   	5.1d
Discussion	Key concepts are defined and by means of everyday language the different representations are linked together properly. However, even though the everyday language usage was done at a high level of competence and fluency, it was the use of expert word (science context specific words) that may have posed an issue (5.1e).	
Expert Words		
Example	drawing of simple circuit, with conventional current, explaining that + charges flow from the positive terminal through circuit into – terminal. (what is hypothesis????) ; (if _____ remains constant????) pronounces ammeter as "*ammameter*" set to show conventional current, switch is on	5.1e

	if we change the units of the ohms to 4, let see what happens – current slows down, 0.75A and bulb less brighter. if we change to resistance of 6 ohms , we get 0.5 A, bulb very dim, charges very slow	
Discussion	While explaining the drawing of the simple circuit diagram (5.1b) and indicating the direction of conventional current the participant incorrectly mentions "that positive charges flow from the positive terminal through circuit into the negative terminal", while it is in actual fact the negative charges that are flowing.	
	The term hypothesis is never defined. The hypothesis also does not mention that there should be a constant when testing the hypothesis.	
	The participant incorrectly pronounces the word ammeter as "ammameter".	
	Participant announces that the switch is turned "on" – this could be confusing when distinguishing between on, off, open and closed.	
	The participant, while changing the resistance on the simulator, incorrectly says "if we change the units of the ohms to 4, ..." – while in actual fact it should say: if we change the magnitude/value of the resistance to 4 ohms.	

This Physics lesson was in general observed to be at a very high level of competence and fluency, however most issues arise from the use of expert words where incorrect terms are used or pronounced incorrectly.

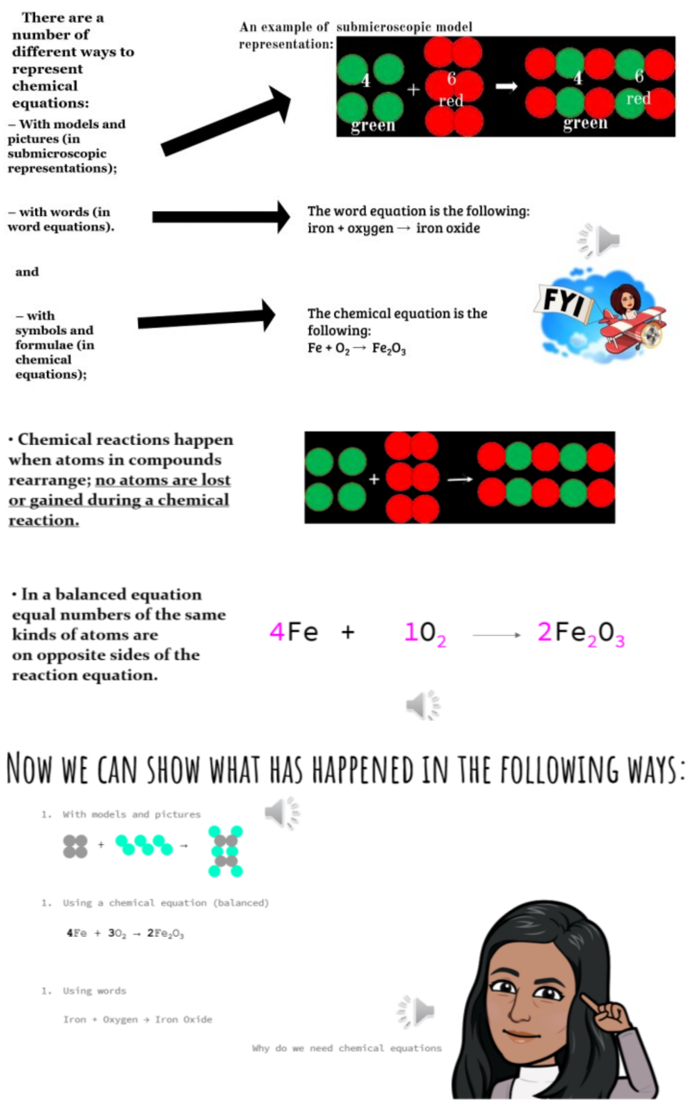
EXAMPLE OF CHEMISTRY LESSON

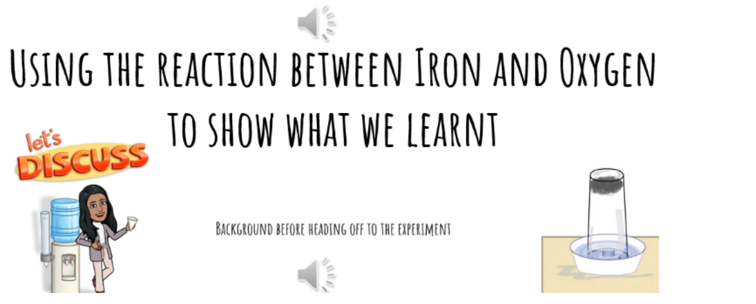
In the table below I focus on and discuss the different representations used in a lesson where the PSST presented on the concept of electrical circuits. The codes obtained for this specific example was as follows:

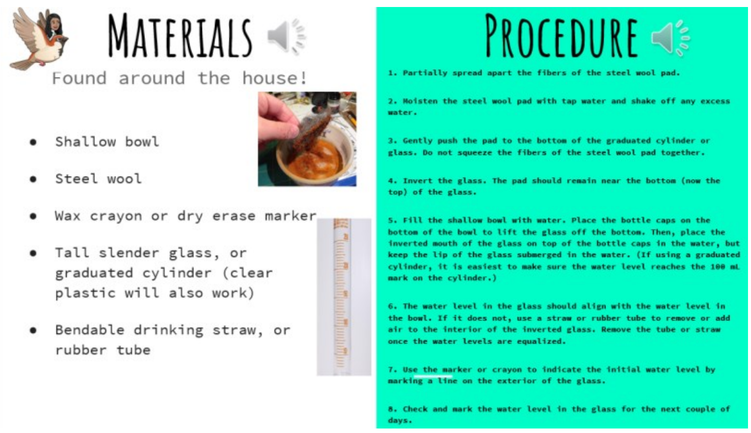
- Code 3 for Graphical Representations
- Code 2 for Experimental Representations
- Code 3 for Symbolic Representations
- Code 3 for Non-specialist Words
- Code 3 for Expert Words

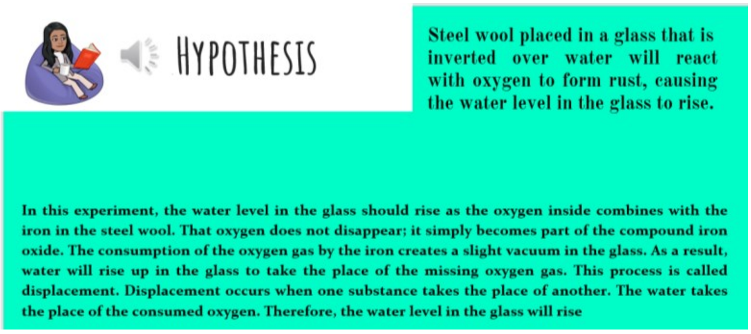
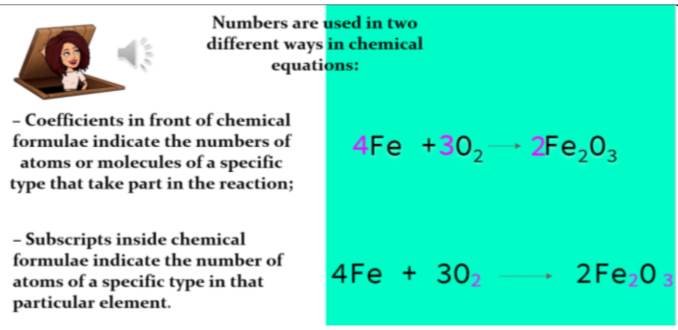
Table 5.2: Example of lesson analysis and coding for a Chemistry lesson presented at a relatively high level of competence and fluency (Unit 35:Group D)

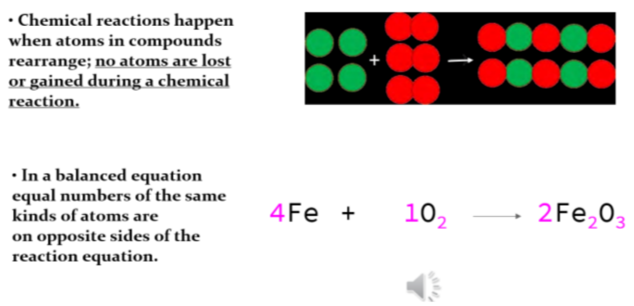
Graphical Representations	

Example		5.2a
Discussion	During this lesson the participant used stick-and-ball diagrams to represent atoms, molecules and balanced chemical equations. This was thoroughly linked to the symbolic representations (5.2c) by means of proper use of Non-specialist and Expert words. Problems that arise from the graphical representations can be seen where the 4 iron atoms are drawn together in the second diagram, this may be misinterpreted as the atoms being bonded to one another. The same happened with the iron oxide represented in the second diagram.	
Experimental Representations		

<table>
<tr><td>Example</td><td>




</td><td>5.2b</td></tr>
<tr><td>Discussion</td><td>There is an experimental element to this lesson, however not practically demonstrated due to time constraints. Results of such an experiment is discussed and linked to the balancing of equations (5.2a and 5.2c). The participant mentions that Steel wool is soft metal filaments, an alloy with very high iron content. Also mentions that (and links partially):
Most Oxygen in our atmosphere is diatomic – 2 atoms bonded together.
Redox reactions – loss or gain of at least 1 electron
Rust – brittle reddish brown substance that forms on the metal.</td><td></td></tr>
<tr><td colspan="2">Symbolic Representations</td><td></td></tr>
<tr><td>Example</td><td>
</td><td>5.2c</td></tr>
</table>

		
Discussion	The balanced equation is represented by means of looking at how numbers influence the balancing, this is linked to the diagrams (5.2a). There is one problem that arise during the use of symbolic representations (5.2c) – in the last diagram the equation is not balanced, but referred to as such.	
Non-specialist Words		
Example		5.2d
Discussion	Generally the everyday language used was done at a high level of competence and fluency and used to link all the different representations together.	
Expert Words		
Example	4 iron molecules (???atoms?) Sub-microscopic – represent what cannot be seen with the eye Symbols – shorten the way of writing What is a hypothesis???	5.2e

Discussion	A few issues that arise from the use of expert words, was the incorrect use of the terms “4 iron molecules” while it should have been 4 iron atoms. Most expert words were defined correctly and used in the correct context. However the term hypothesis was never defined and could have been confusing.	

This Chemistry lesson was in general observed to be at a relatively high level of competence and fluency, however most issues arise from the use of graphical representations that where incorrect and may have caused confusion or inhibit correct learning. The lack of the hands-on demonstration of the proposed experiment also decreased the overall level of competence and fluency of the lesson.

Below is a short discussion on the results and observations made during the initial coding of the data for each one of the different groups. One example will be discussed briefly for each one of the groups. Since different assignments were prescribed for the different groups, the context and requirements of these assignments were considered for this discussion.

5.2.1 GROUP A LESSON PRESENTATIONS: SERIES/PARALLEL CIRCUITS (n=40)

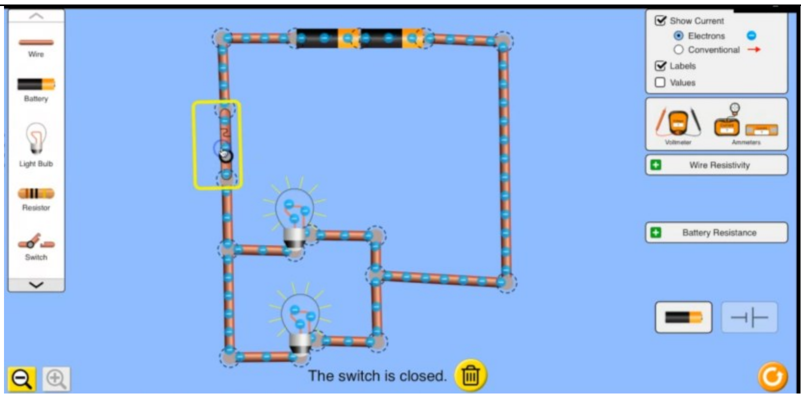
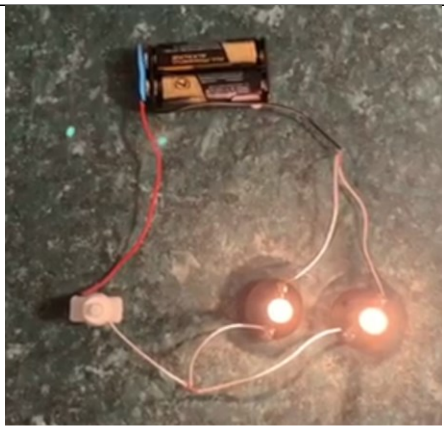
Group A had to present a lesson on electric circuits, which is identified as a Physics concept in the CAPS curriculum. The assignment the participants of this group received for the lesson preparation and presentation can be viewed in Addendum G.

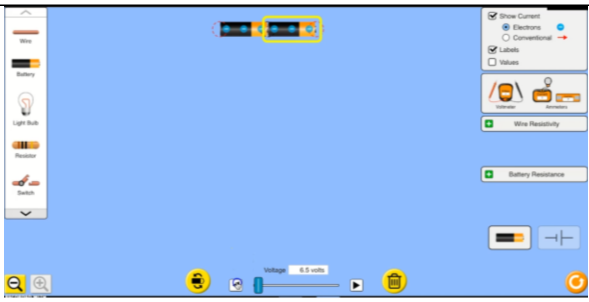
From the coded data for Group A (Table 4.1) the following can be observed: Only 40% of participants showed high levels of competence and fluency when using graphical representations, while 12% used no graphical representation whatsoever. No symbolic representations was used by 77,5% of participants and only 5% used such representations at a high level of competence and fluency. On average participants scored low level (35%) or medium level (47,5%) competence and fluency codes when using experimental representations. When using everyday language and literacy participants mostly proved competent and fluent on a medium to high level (35% and 37,5% respectively), while only 2,5% of those participants functioned on a high level when using science specific terms and 67,5% used science specific terms on a low level.

Below is an example of a lesson presentation discussed for Group A participants. This example was identified as to reflect the general observations for this group. The general observations for Group A can be described as a lesson presentation having a:

- Code 3 for Graphical Representations
- Code 2 for Experimental Representations
- Code 0 for Symbolic Representations
- Code 3 for Non-specialist Words
- Code 1 for Expert Words

Table 5.3: Example of lesson analysis and coding for a lesson presented at a representative level of competence and fluency for Group A (Unit 3: Group A)

Graphical Representations		
Example		5.3a
Discussion	A simulator was used to build a graphical version of the experimental circuit. The building and functioning of the circuit by means of a simulator was done at a high level of competence and fluency and explained verbally better through everyday language (5.3d) than using science specific terms (5.3e)	
Experimental Representations		
Example		5.3b
Discussion	The hands-on model that was built and used as an example to build the simulator circuit was not linked enough to other representational modes, but was only linked to the circuit simulator (5.3a) by means of words.	
Symbolic Representations		
Example	NO EVIDENCE	5.3c
Non-specialist Words		
Example	Linking of 5.3a and 5.3b was done in an informal language that is understandable and relatable.	5.3d

Discussion	The use of everyday language to verbally explain the graphical and experimental representations was done at a high level of competence and fluency. There was no written text evident during the lesson presentation other than labelling the components in the circuit simulator.	
Expert Words		
Example	 The PSST refers to using two "batteries" and that one must specify volts value for the battery. Names the conducting wire a medium that current can flow through. The switch controls the flow of electrons through the circuit (open & closed circuit – defined) appliance – lightbulb (resistor???) electrons flow from negative terminal through the circuit parallel* – electron divided equally , because same resistance reaches + terminal source of power to supply energy to allow for flow of current	5.3e
Discussion	The term "batteries" was used instead of cells. The participant also refers to the battery's "volts value" instead of its potential difference or emf. Words that can have different meanings in different contexts such as "medium", "terminal" and "power" were not defined. It is also not specified which path the electrons flow through, just that it flows from the negative terminal and that it reaches the positive terminal – does not refer to electron flow vs conventional current. In general the expert words used were not linked properly to the content of the lesson and it does not seem as if it contributed to the explanation of the science concept.	

The results obtained for Group A could potentially be ascribed to the fact that the assignment (Addendum G) specifically stated that the PSSTs should make use of a simulation, hence the high level of competence and fluency compared to the other representational modes.

5.2.2 GROUP B LESSON PRESENTATIONS: VISIBLE LIGHT (n=34)

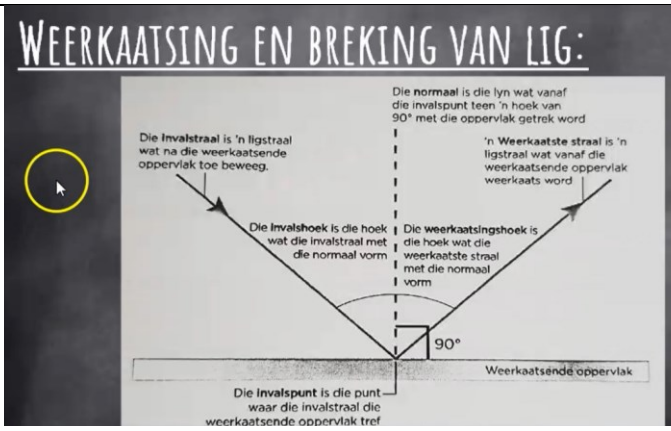
Group B had to complete and present a lesson on visible light, which is identified as a Physics concept in the CAPS curriculum. The assignment the participants of this group received for the lesson preparation and presentation can be viewed in Addendum H.

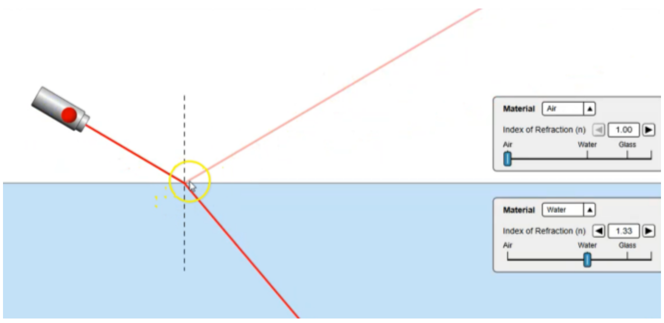
From the coded data for Group B (Table 4.2) the following can be observed: Of those participants who used a graphical representation 47,1% and 35,3% did so at a medium or high level respectively. 50% of participants did not use experimental representations, but of those who did most (29,4%) did so at a medium level of competence and fluency. 97,1% of participants did not use any symbolic representation, while those who did all were done at medium level. All participants used non-specialist and expert words, however the use of non-specialist words were coded to mostly (64,7%) be on a high level while the expert words were found to be used on a medium level (52,9%).

Below is an example of a lesson presentation discussed for Group B participants. This example was identified as to reflect the general observations for this group. The general observations for Group B can be described as a lesson presentation having a:

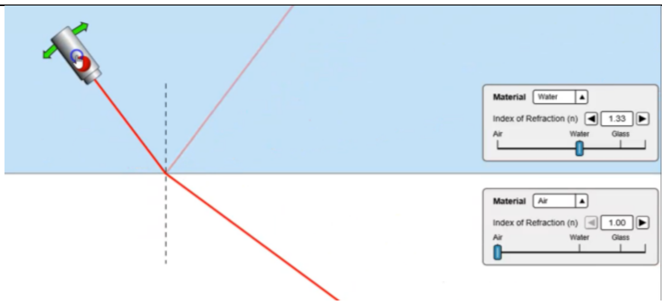
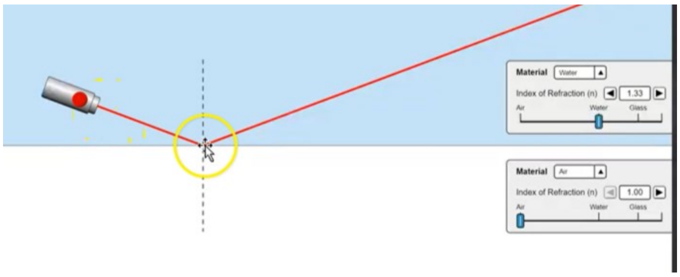
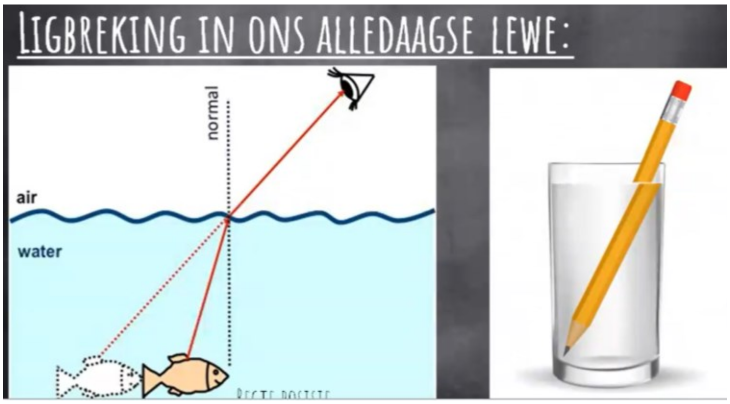
- Code 2 for Graphical Representations
- Code 0 for Experimental Representations
- Code 0 for Symbolic Representations
- Code 3 for Non-specialist Words
- Code 2 for Expert Words

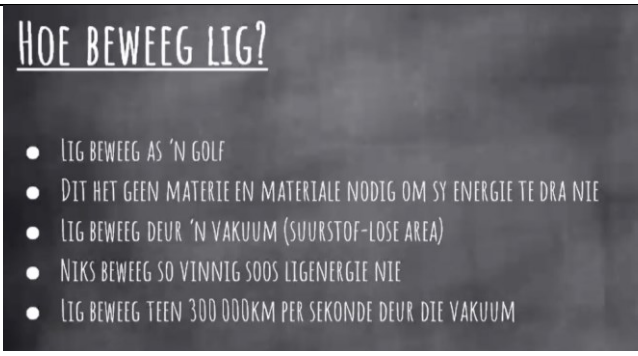
Table 5.4: Example of lesson analysis and coding for a lesson presented at a representative level of competence and fluency for Group B (Unit 28:Group B)

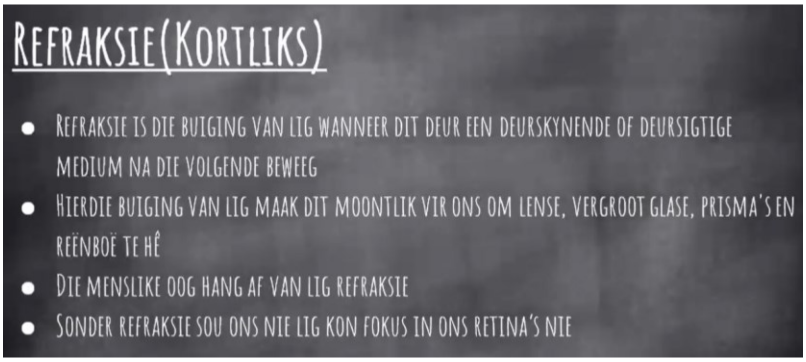
<table>
<tr><td colspan="2">Graphical Representations</td><td></td></tr>
<tr><td>Example</td><td>




</td><td>5.4a</td></tr>
</table>

	    	
Discussion	Although a simulator and diagrams were used to show reflection and refraction, these two representations were only linked to some extent and not in its entirety. Both these representations and the principles they were supposed to represent were discussed successfully (5.4d), but without an experimental or symbolic component, the overall fluency was lacking.	
Experimental Representations		
Example	NO EVIDENCE	5.4b
Symbolic Representations		
Example	NO EVIDENCE	5.4c
Non-specialist Words		

<table>
<tr><td>Example</td><td>




</td><td>5.4d</td></tr>
<tr><td>Discussion</td><td>The discussion took place in written and spoken words explaining the difference between reflection and refraction to some extent. The fluency between the two graphical representations used (5.4a) is due to the appropriate use of words.</td><td></td></tr>
<tr><td colspan="2">Expert Words</td><td></td></tr>
<tr><td>Example</td><td>Light travels through a vacuum (oxygen free area)
Density vs Optical Density?
Heading mentions refraction, but shows only reflection.</td><td>5.4e</td></tr>
<tr><td>Discussion</td><td>There are science specific terms used such as “medium”, “refraction”, “reflection” and “optical density”. A few aspects of this could have subtracted from the success</td><td></td></tr>
</table>

	of the lesson presentation, such as not distinguishing between density and optical density. A vacuum is also defined as an oxygen free area, which may be interpreted as having other substances or gasses present but not oxygen. One of the headings also refers to Reflection and Refraction, but then only a graphical representation of reflection is present (5.4a).	

The results obtained for Group B could potentially be ascribed to the fact that the assignment specifically stated that the PSSTs should make use of the grade 8 curriculum. The grade 8 curriculum is set out to focus on graphical representations of visible light related phenomena. The symbolic representations here would only be used in grade 9 and higher, hence the low symbolic representational competence and fluency. What is notable is the fact that most PSSTs did not use experimental representations to explain the concept of visible light, even though this is a highly practical phenomenon. The rubric and instructions (Addendum H) do not mention any practical (macroscopic) requirements, and only focus on the explanation of the microscopic.

5.2.3 GROUP C LESSON PRESENTATIONS: MATTER AND MATERIALS (n=38)

Group C had to present a lesson on matter and materials, which is identified as a Chemistry concept in the CAPS curriculum. The assignment the participants of this group received for the lesson preparation and presentation can be viewed in Addendum I.

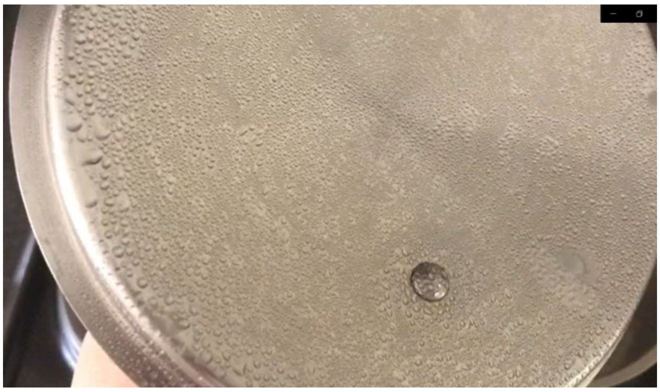
From the coded data for Group C (Table 4.3) the following can be observed: 79,8% and 94,7% of participants did not use graphical and symbolic representations respectively. Those who did use graphical representations mostly (18,4%) did so on a medium level of competence and fluency. Most participants who used an experimental representation did so at a medium level (44,7%) or a high level (34,2%), which was almost similar to the use of non-specialist words on a medium level (44,7%) and high level (36,8%). Only 5,3% of participants used expert words on a high level of competence and fluency, while 23,7% did not use any expert or science context specific words.

Below is an example of a lesson presentation discussed for Group C participants. This example was identified as to reflect the general observations for this group. The general observations for Group C can be described as a lesson presentation having a:

- Code 0 for Graphical Representations
- Code 2 for Experimental Representations
- Code 0 for Symbolic Representations
- Code 2 for Non-specialist Words
- Code 2 for Expert Words

Table 5.5: Example of lesson analysis and coding for a lesson presented at a representative level of competence and fluency for Group C (Unit 35: Group C)

Graphical Representations		
Example	NO EVIDENCE	5.5a
Experimental Representations		
Example	 	5.5b

	 	
Discussion	The PSST takes ice and put it inside a pot on the stove and explains the phase changes that takes place when the ice melt, starts to boil and evaporate. During the experiment the PSST refers to the phases of water and the process by mean of everyday language and does not entirely link the macroscopic observations to the microscopic happenings, but does refer to the energy of the molecules and the spaces in between them (5.5d).	
Symbolic Representations		
Example	NO EVIDENCE	5.5c
Non-specialist Words		
Example	Molecules have energy to spread out and move away from one another as it melts. The ice completely melted to become a liquid and as it heats up further it changes to a gas. Water is busy to bubble which means it is close to its boiling point (100 degrees Celsius). The temperature of steam is 100 degrees Celsius which means that steam is just as hot as boiling water. Water thus has three phases.	5.5d
Discussion	The PSST explains what it going on during the experiment, but only refers to the microscopic level in the beginning of the lesson when the ice is melting. If not for the use of the everyday language the experiment (5.5b) would not have had any context.	
Expert Words		

Example	Put on the lid for a while and the water molecules will stick to the lid in liquid form. Gas that changes to liquid is called condensation and the phase we have here is condensation.	5.5e
Discussion	The PSST uses terms such as "phases", "condensation" and "energy", but inaccurately in the case of condensation. This term is insinuated to be a phase instead of a process of phase change. The PSST also refers to the liquid water molecules as sticking to the lid, without explaining exactly what happens and why and does not refer to phase change for this observation.	

In Addendum I it is stated that the PSSTs must do a practical demonstration on the concept, make a video recording and explain what is observed. This may then clarify why most of the PSSTs did not use any graphical or symbolic representations, but mostly only experimental representations (practical demonstrations) and language (explain) were used.

5.2.4 GROUP D LESSON PRESENTATIONS: CHEMICAL REACTIONS (n=43)

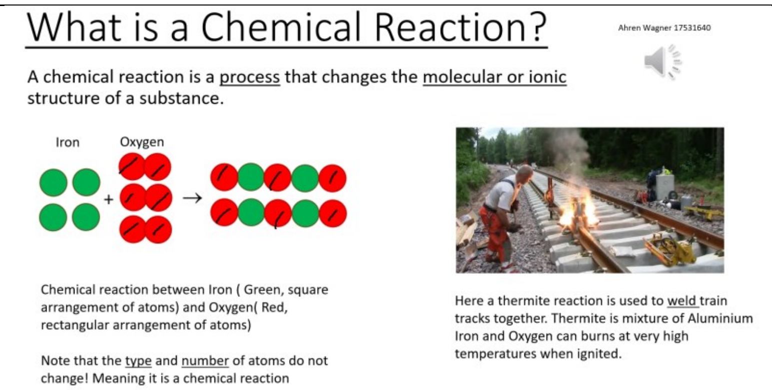
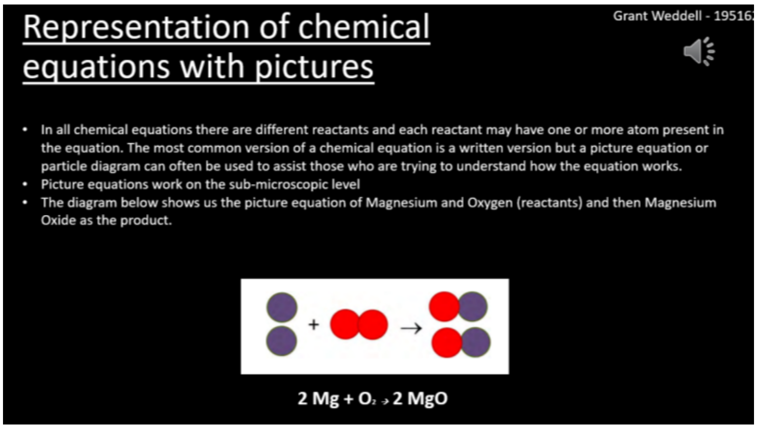
Group D had to present a lesson on chemical reactions, which is identified as a Chemistry concept in the CAPS curriculum. The assignment the participants of this group received for the lesson preparation and presentation can be viewed in Addendum J.

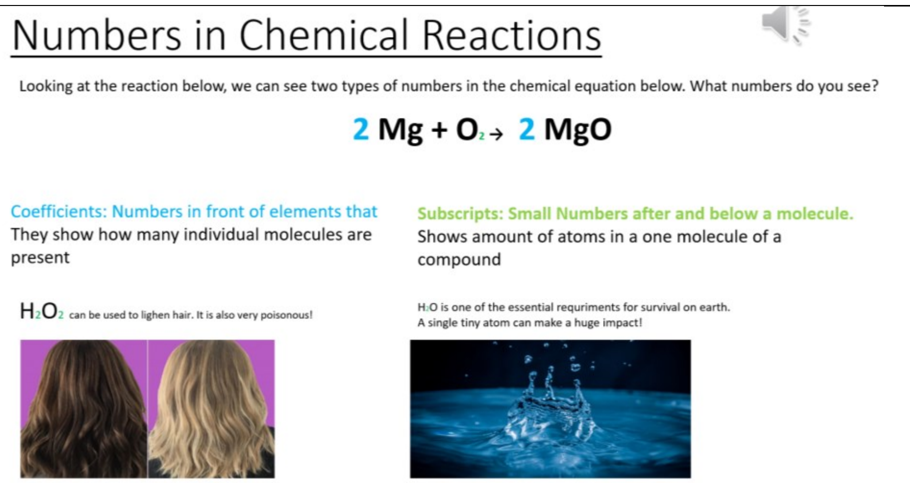
From the coded data for Group D (Table 4.4) the following can be observed: On average most (53,5%) participants used symbolic representations on a medium level of competence and fluency. In terms of graphical representations it was observed that 44,2% of participants managed to incorporate these on a medium level and 32,6% on a low level. 20,9% of participants did not use any experimental representation, while 46,5% did so at a low level. All participants used expert words during their lesson presentations, but mostly on a medium level (60,5%) or a low level (25,6%).

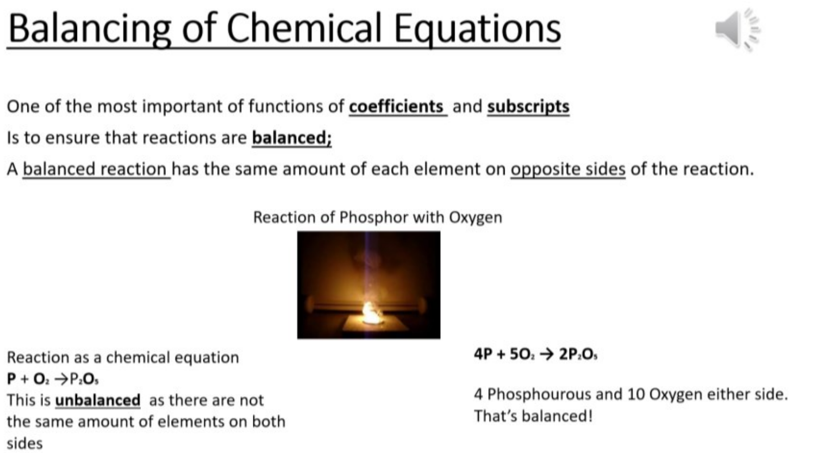
Below is an example of a lesson presentation discussed for Group D participants. This example was identified as to reflect the general observations for this group. The general observations for Group D can be described as a lesson presentation having a:

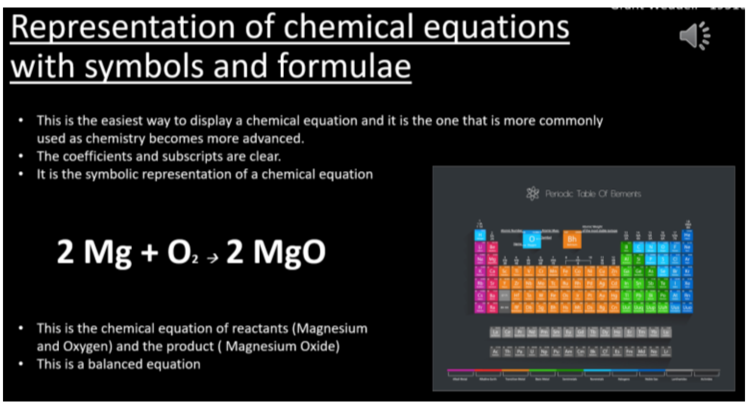
- Code 2 for Graphical Representations
- Code 1 for Experimental Representations
- Code 2 for Symbolic Representations
- Code 3 for Non-specialist Words
- Code 2 for Expert Words

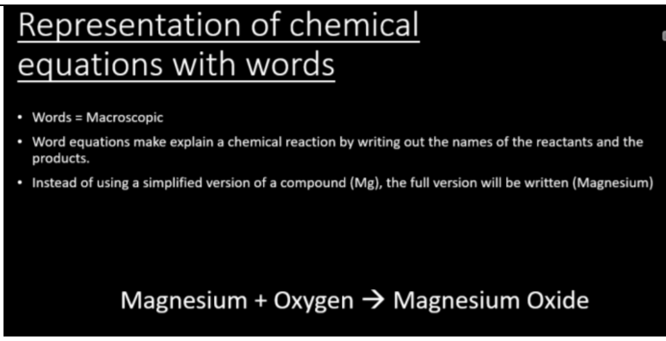
Table 5.6: Example of lesson analysis and coding for a lesson presented at a representative level of competence and fluency for Group D (Unit 2: Group D)

Graphical Representations		
Example	 	5.6a
Discussion	The graphical representation in the first diagram is balanced visually, but not symbolically or by means of words. It is also not elaborated on why it is balanced visually. No links are made to this specific diagram. The second example is however linked to symbolic by means of both non-specialist and expert words (5.6d and 5.6e)	
Experimental Representations		
Example	 	5.6b
Discussion	There is reference to burning of metals in oxygen and the flames it produce, however this is not successfully linked to the other representations as to explain why this phenomenon is observed.	
Symbolic Representations		

<table>
<tr><td>Example</td><td>




</td><td>5.6c</td></tr>
<tr><td>Discussion</td><td>The chemical equations are partially linked to the theory by means of a graphical representation (5.6a), but mostly through the use of language, especially everyday language (5.6d).</td><td></td></tr>
<tr><td colspan="2">Non-specialist Words</td><td></td></tr>
<tr><td>Example</td><td>*see all other screenshots in this table</td><td>5.6d</td></tr>
<tr><td>Discussion</td><td>All of the slides contains everyday language as to create the context for a specific representation used and links all of the content together.</td><td></td></tr>
<tr><td colspan="2">Expert Words</td><td></td></tr>
</table>

<table>
<tr><td>Example</td><td>
</td><td>5.6e</td></tr>
<tr><td>Discussion</td><td>Terms such as “reactants”, “products” and “chemical equations” are used often linked to the content. Word equations to describe the reactants and products are used, but incorrectly uses capital letters. The terms “coefficients” and “subscripts” are used to link the symbolic to the graphical too (5.6c).</td><td></td></tr>
</table>

This assignment (Addendum J) instructed the PSSTs to choose one of two applications of chemical reactions and to explain certain key concepts for the chosen application. The notes and outline they received focuses on a variety of ways to represent chemical equations, especially graphical and symbolic representations. This could explain why the representational mode with the lowest level of competence and fluency was experimental representations. Another potential reason could be the availability of substances to demonstrate the reactions as well as potential safety hazards.

5.2.5 GROUP E VIDEO RECORDINGS: PHYSICS (n=9)

Group E had to present a lesson on a topic which is identified as a Physics concept in the CAPS curriculum.

From the coded data for Group E (Table 4.5) the following can be observed: All participants made use of graphical representations, but no high level attempts was documented. Most (77,8%) of these graphical representations were integrated on a medium level. Of those (88,8%) who included an experimental representation, half (44,4%) did this at a high level of competence and fluency. 66,7% of participants did not make use of any symbolic representations during their lesson presentations. 44,4% of participants used both non-specialist and expert words on a medium level, but 55,6% used non-specialist words on a high level while only 33,3% used expert words on the same level.

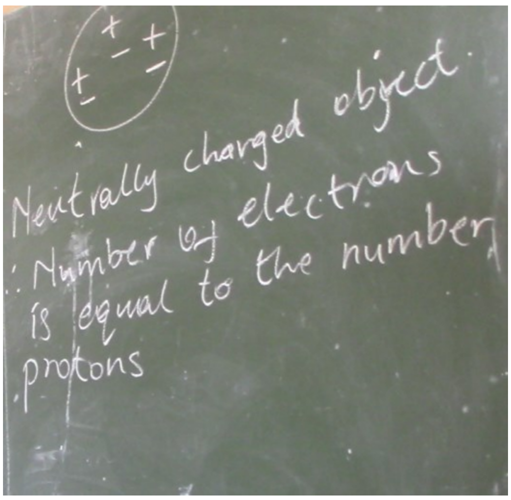
Below is an example of a lesson presentation discussed for Group E participants. This example was identified as to reflect the general observations for this group. The general observations for Group E can be described as a lesson presentation having a:

- Code 2 for Graphical Representations
- Code 3 for Experimental Representations
- Code 0 for Symbolic Representations

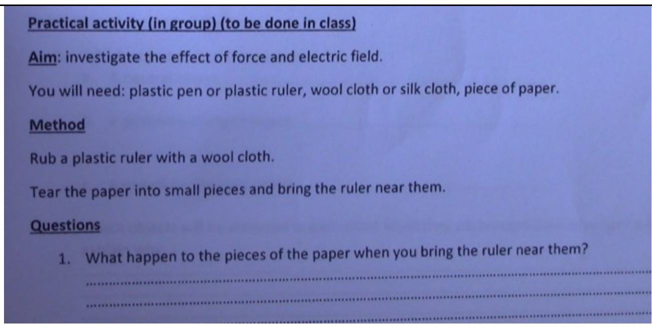
- Code 3 for Non-specialist Words
- Code 2 for Expert Words

Table 5.7: Example of lesson analysis and coding for a lesson presented at a representative level of competence and fluency for Group E (Unit 6: Group E)

<table>
<tr><td colspan="2">Graphical Representations</td><td></td></tr>
<tr><td>Example</td><td>



</td><td>5.7a</td></tr>
<tr><td>Discussion</td><td>The PSST explains electrostatics and electron transfer by means of diagrams indicating positive and negative charges. These diagrams are also used to explain</td><td></td></tr>
</table>

<table>
<tr><td></td><td>forces of repulsion and attraction in electrostatics. This is demonstrated in the practical investigation (5.7b) and linked together with spoken and written words.</td><td></td></tr>
<tr><td colspan="2">Experimental Representations</td><td></td></tr>
<tr><td>Example</td><td>


Practical activity (in group) (to be done in class)

Aim: investigate the effect of force and electric field.

You will need: plastic pen or plastic ruler, wool cloth or silk cloth, piece of paper.

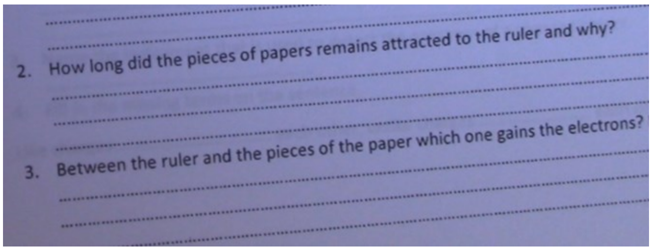
Method

Rub a plastic ruler with a wool cloth.

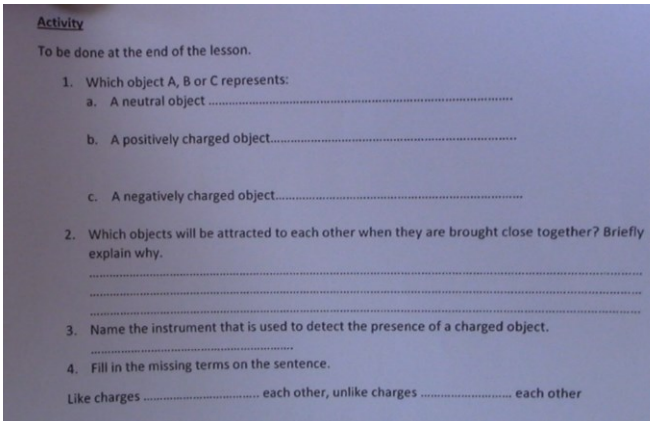
Tear the paper into small pieces and bring the ruler near them.

Questions

1. What happen to the pieces of the paper when you bring the ruler near them?



2. How long did the pieces of papers remains attracted to the ruler and why?
3. Between the ruler and the pieces of the paper which one gains the electrons?

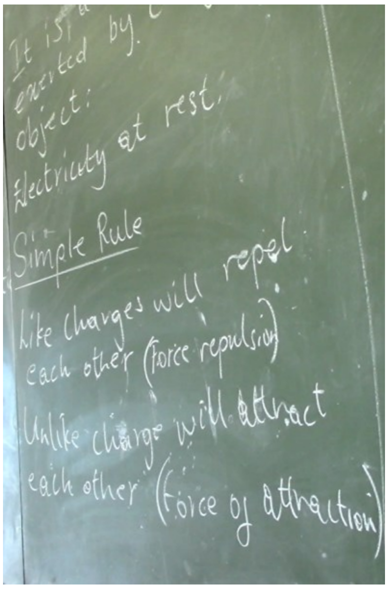


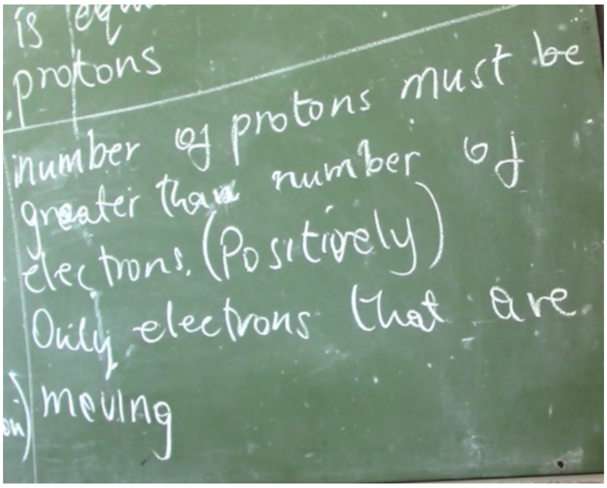
Activity

To be done at the end of the lesson.

1. Which object A, B or C represents:
   a. A neutral object ……
   b. A positively charged object……
   c. A negatively charged object……
2. Which objects will be attracted to each other when they are brought close together? Briefly explain why.
3. Name the instrument that is used to detect the presence of a charged object.
4. Fill in the missing terms on the sentence.

Like charges …… each other, unlike charges …… each other
</td><td>5.7b</td></tr>
<tr><td>Discussion</td><td>The PSST instruct the learners to rub rulers and pens against school jerseys (wool) and try to pick up small pieces of paper, but it is not really working. The PSST assumes the jerseys are made of wool.
Learners eventually decide by themselves to rub the pens and rulers against their hair and the experiment works – facilitator then explains that the jerseys must be made of synthetic fibres, but not why that may influence the results. The results are linked to the graphical (5.7a) by means of spoken and written language (5.7d and 5.7e).</td><td></td></tr>
<tr><td colspan="2">Symbolic Representations</td><td></td></tr>
<tr><td>Example</td><td>NO EVIDENCE</td><td>5.7c</td></tr>
<tr><td colspan="2">Non-specialist Words</td><td></td></tr>
</table>

<table>
<tr><td>Example</td><td>


</td><td>5.7d</td></tr>
<tr><td>Discussion</td><td>The teacher teaches in a very relatable manner and uses short and straight forward language when writing on the board. The words used are immediately linked to either the graphical (5.7a) or the experimental (5.7b) representations they describe.</td><td></td></tr>
<tr><td colspan="2">Expert Words</td><td></td></tr>
<tr><td>Example</td><td>Forces: contact and non-contact
Electrostatic forces: electricity, electrons (negative particle in an atom), stationary or at rest, static – addressing language links very well.
Def: non-contact force exerted by a charged
Only electrons are moving
Heading of activity</td><td>5.7e</td></tr>
<tr><td>Discussion</td><td>The theme of the lesson is identified as contact and non-contact forces, however the PSST does not distinguish between the two. Electrostatic forces are defined well in terms of what is observed macroscopically and how it may be explained microscopically. The teacher mentions that it is only electrons that move and causes charge, this could have been demonstrated at a higher level graphically. The heading of the activity refers to “electric field” without ever referring to it during the course of the lesson.</td><td></td></tr>
</table>

This lesson was presented at a township school with very little resources. The PSST utilized the chalkboard to write notes and draw diagrams. English is not the learners' home language so the PSST used simple everyday language to explain the concepts. A good link was made to a practical experience of forces of attraction to drive the concept of electrostatic forces of attraction home. The context in which the lesson takes plain also explains why the PSST did not overelaborate through the use of expert words.

5.2.6 GROUP F VIDEO RECORDINGS: CHEMISTRY (n=3)

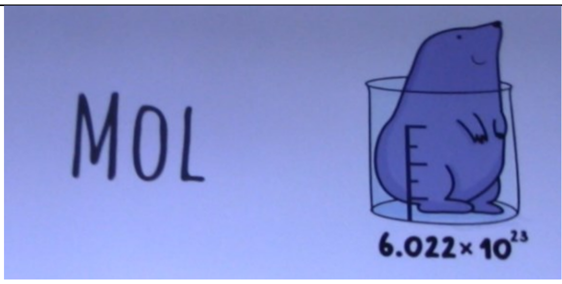
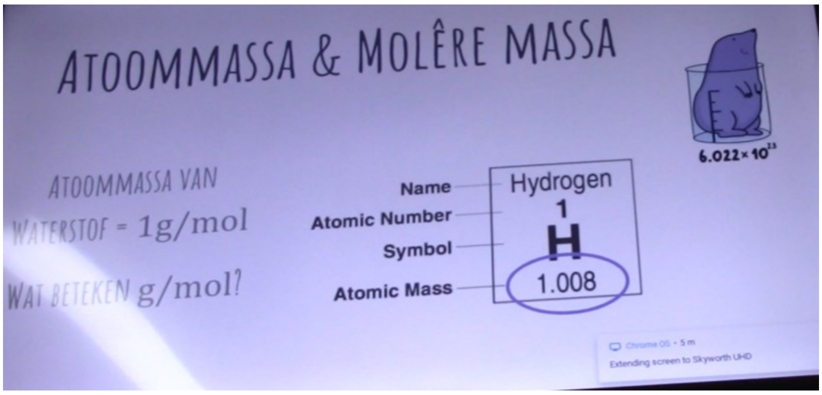
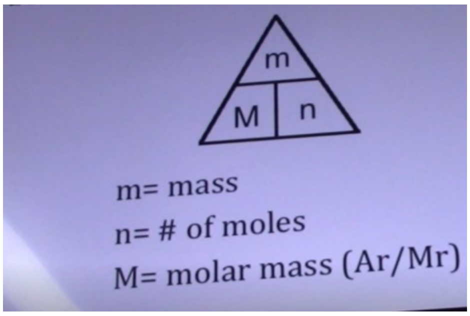
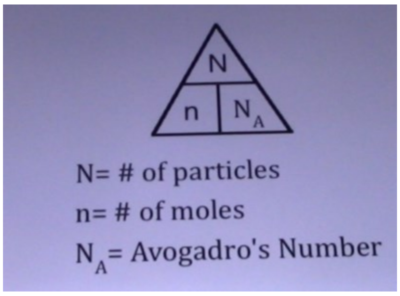
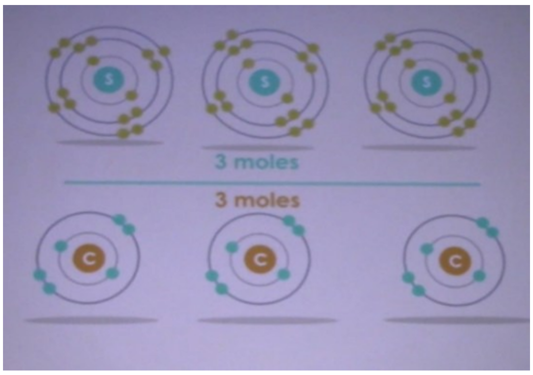
Group F had to present a lesson on a topic which is identified as a Chemistry concept in the CAPS curriculum.

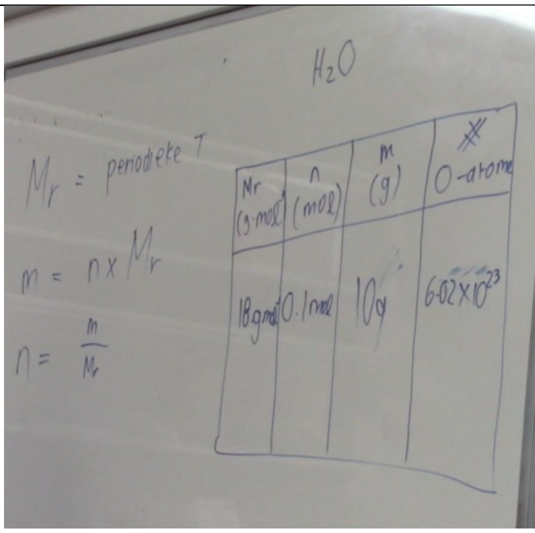
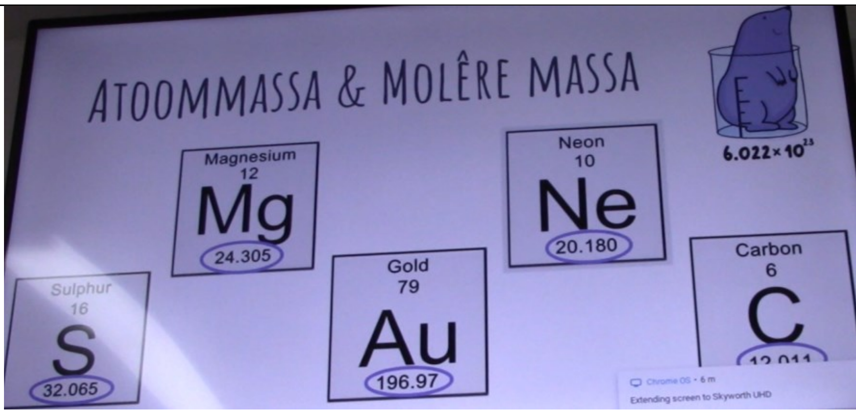
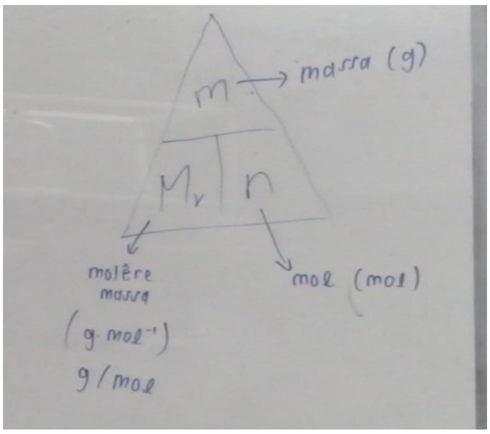
From the coded data for Group F (Table 4.6) the following can be observed: None of the participants included any experimental representation during their lesson presentations and 33,3% did not incorporate symbolic representations. In terms of the use of graphical and symbolic representations as well as non-specialist words, 66,7% of participants did so at a high level for each one of these three representational modes. All participants used expert words during their lessons, however all three levels of competence and fluency was recorded as being present in equal amounts (33,3%).

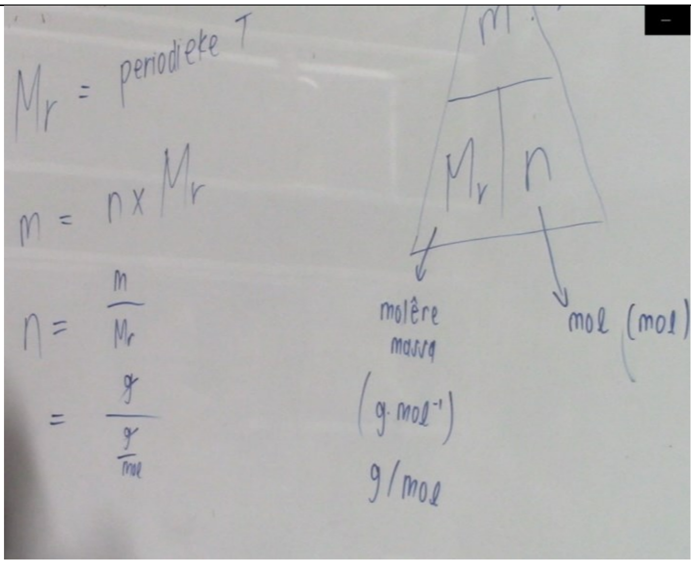
Below is an example of a lesson presentation discussed for Group F participants. This example was identified as to reflect the general observations for this group. The general observations for Group F can be described as a lesson presentation having a:

- Code 3 for Graphical Representations
- Code 0 for Experimental Representations
- Code 3 for Symbolic Representations
- Code 3 for Non-specialist Words
- Code 1 or 2 or 3 for Expert Words (will look at an example where Code 3 was observed)

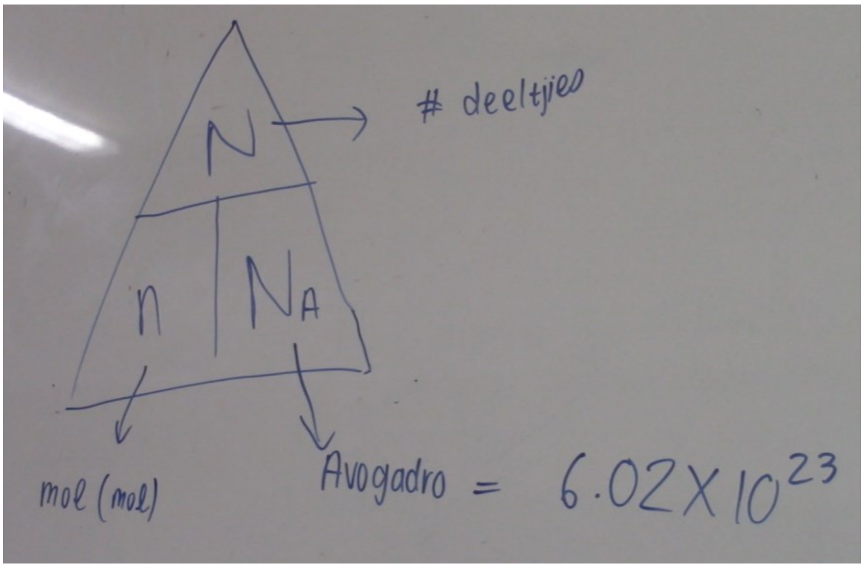
Table 5.8: Example of lesson analysis and coding for a lesson presented at a representative level of competence and fluency for Group F (Unit 3: Group F)

Graphical Representations		
Example	    	5.8a

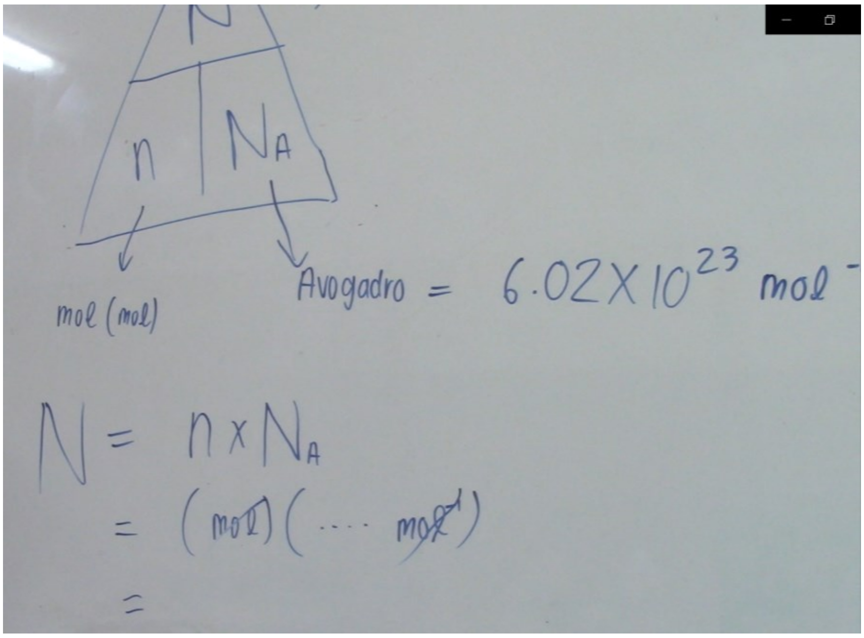
		
Discussion	The PSST used various graphical representations to demonstrate mole and related concepts and relationships. Very well linked to the symbolic and language representations. The energy level diagram used to represent 3 moles of each substance, may be confusing and misinterpreted if seen on its own out of context. This diagram was however used directly after using the 3 bags of sweets analogy (5.8d) in which context it could make sense.	
Experimental Representations		
Example	NO EVIDENCE	5.8b
Symbolic Representations		
Example	 	5.8c



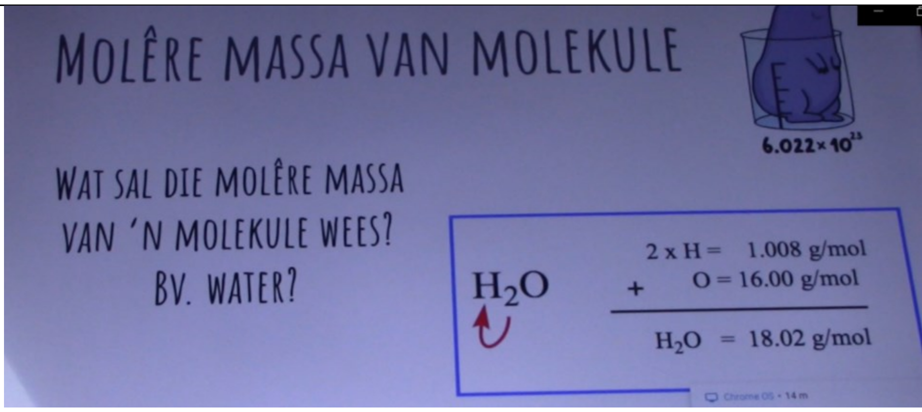
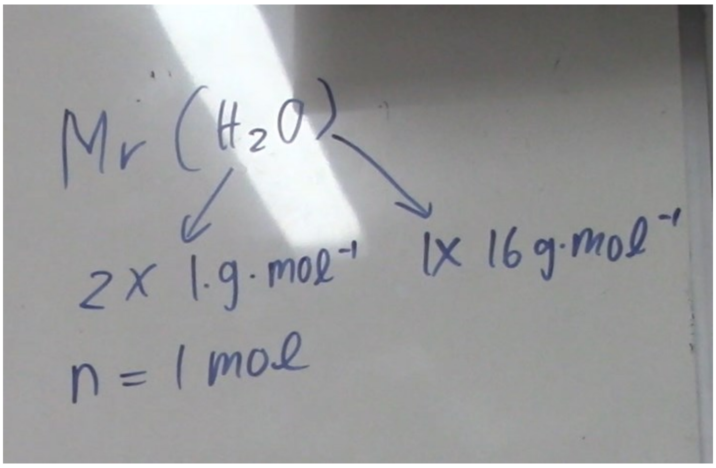
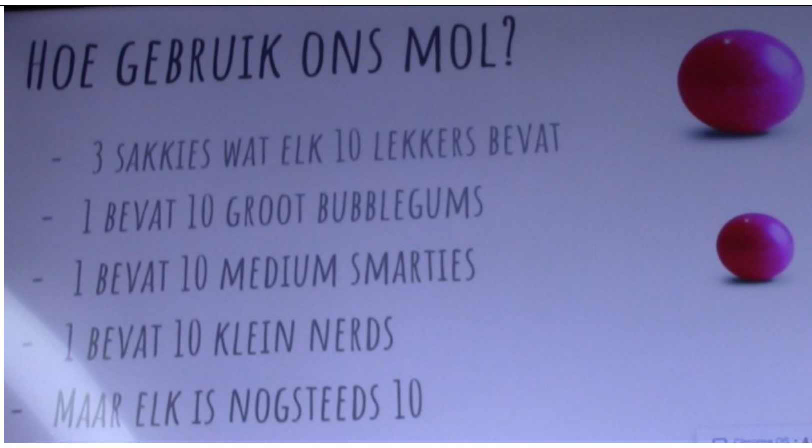
Mr = periodieke T
m = n x Mr
n = m / Mr
= g / (g/mol)
Mr | n
molêre massa
(g·mol-1)
g/mol
mol (mol)

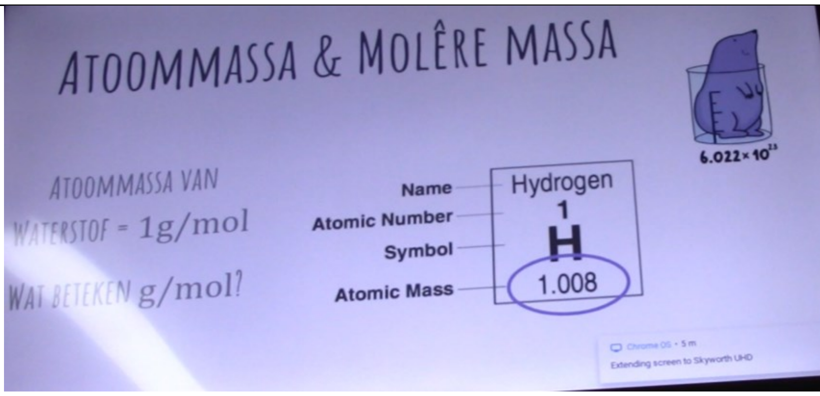


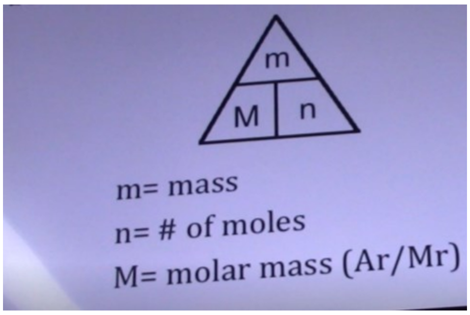
N
deeltjies
n | NA
mol (mol)
Avogadro = 6.02X10 23

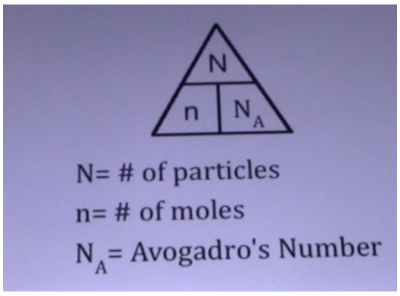


n | NA
mol (mol)
Avogadro = 6.02X10 23 mol -
N = n x NA
= (mol)(.... mol-1)
=

	  	
Discussion	Formulas used were successfully linked to the graphical representations by means of language usage. The PSST explained which aspects of the formulas relates to the macroscopic (mass) and which aspects to the microscopic (moles), and how microscopic changes may result in macroscopic changes as well. The units of measurement are verified using the mathematical equations.	
Non-specialist Words		
Example	 	5.8d
Discussion	Overall the use of non-specialist words and relatable language is used to describe the mole concept. An analogy is used to explain moles. The PSST argues when one has three bags of sweets, one with 10 gumballs, one with 10 smarties and one with 10 nerds-sweets, you still have three bags with 10 sweets in it. The PSST then continues to say it does not matter what type of substance (sweet) we have, when we have one mole (one bag) we have 6,02x10^{23} particles (10 sweets).	

<table>
<tr><td colspan="2">Expert Words</td><td></td></tr>
<tr><td>Example</td><td>






</td><td>5.8e</td></tr>
<tr><td>Discussion</td><td>Terms such as “mole”, “mass”, “number of particles”, “Avogardo’s constant” etc is used throughout and thoughtfully. No term was used incorrectly and out of context. The meaning of each term as intended.</td><td></td></tr>
</table>

In general it can be seen that these PSSTs did not make use of experimental representations to explain certain Chemistry concepts. As discussed earlier this may be due to availability of substances to demonstrate the reactions as well as potential safety hazards. Another reason may have been time constraints, since the lessons presented were only allowed a specific time determined by the school’s lesson duration. It must also be acknowledged that some of the schools may not have the facilities to do practical demonstrations. Lastly, costs involved to acquire materials to do practical work may put off PSSTs to do so where the schools do not provide this.

A general observation from the results obtained in this section point towards the role the assignment and explicit instructions indicated on the assignment may influence the representational modes used to explain a specific science concept, and thus influencing the PCK of the PSST. McCollum, Sepulveda and Moreno (2016) found that the type of representational technology a facilitator decides, instructs or prefer to use will influence the strategies they use to solve problems or explain concepts and this could potentially explain why certain representational modes were preferred by the PSSTs during their lesson presentations since they have to some extent been guided by the assignments as set up by the facilitator as well as the teachings and training presented to these PSSTs by the facilitator.

From the discussion above I attempt to lay out how I interpreted the data when coding and once coded and how these observations made from the initial coding of the data were used to attempt to answer the four sub-questions of the study. The coded data was analysed qualitatively and quantitatively and in the next four sections the findings will be discussed.

5.3 Different Modes of Representation Used Explicitly

This section aims to answer the following research sub-question:

a) What are the different modes of representation that pre-service science teachers explicitly use during lessons?

It is important to note for the interpretation of the results in Section 4.3 (Chapter 4) that the use of a specific representational mode does not necessarily imply proper use and integration of this representation in the lesson, as any attempt of a representational mode was coded as either low-level, medium-level or high-level. Where there was no evidence of a representational mode at all, a no attempt code was assigned and ignored in this section for the purpose of this interpretation. Thus, where codes 1, 2 and 3 were assigned the results were combined as evidence of a representational mode used.

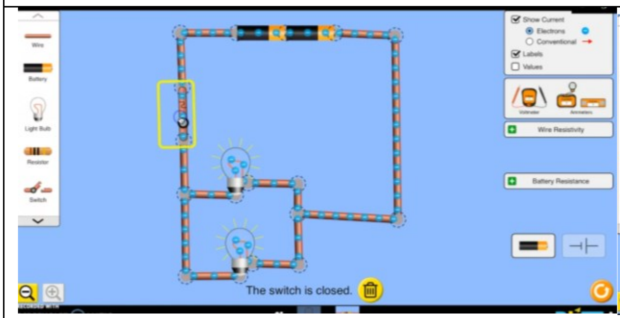
5.3.1 Different Modes of Representation Used in Physics

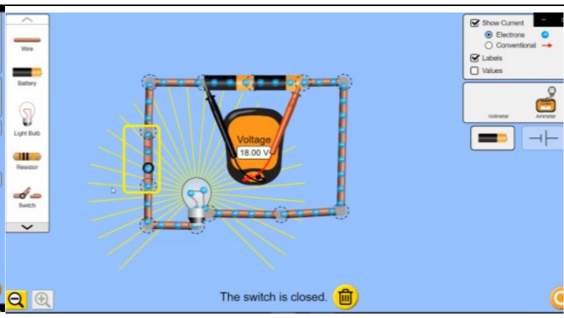
From Table 4.7 it is evident that none of the representational modes were not used at all in the analysed Physics lessons. One can also conclude that the modes that was used most prominent in Physics are Non-specialist Words (97,59%), Graphical representations (91,57%) and Expert Words (91,57%). While Experimental representations (74,70%) were also used often, Symbolic representations (15,66%) were mostly lacking evidence of use during these lessons.

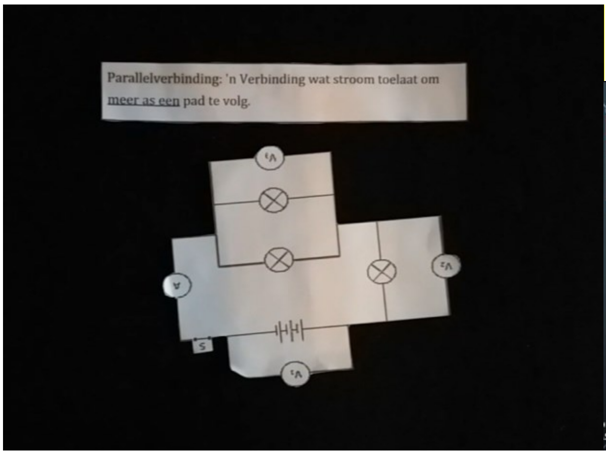
In Table 5.9 below examples of these representational modes used can be seen, excluding Non-specialist and Expert Words as this is seen as embedded in all the other representational modes and elaborated on in Section 5.6.

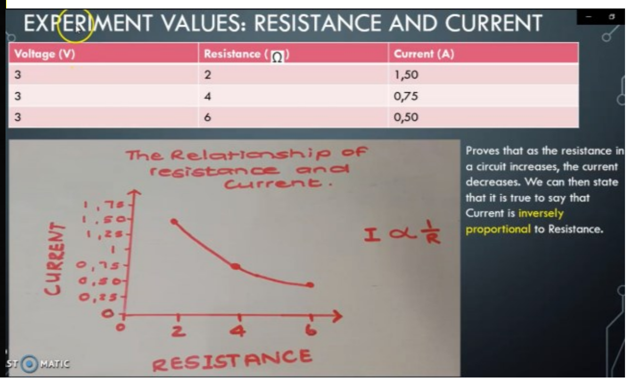
Table 5.9: Examples of the representations observed in the Physics lessons classified under the relevant representational mode

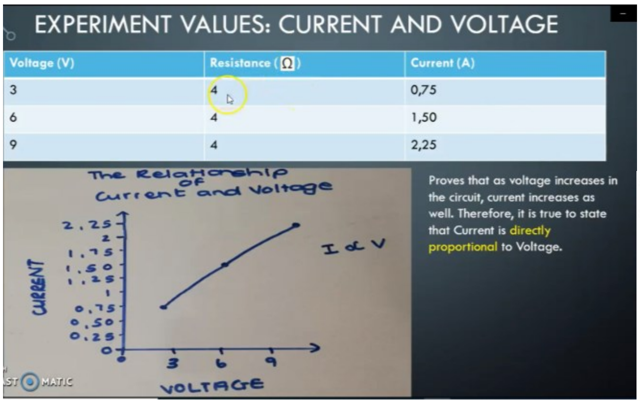
Graphical Representations

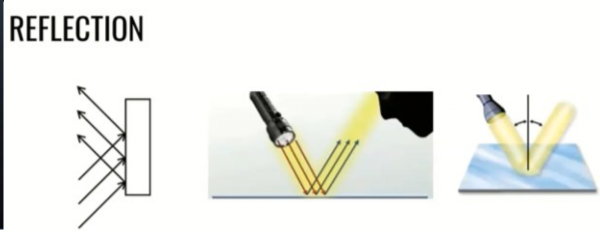


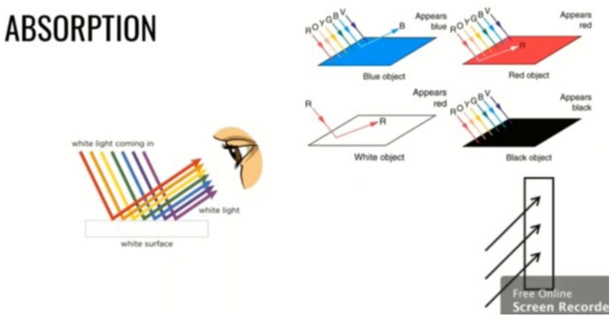


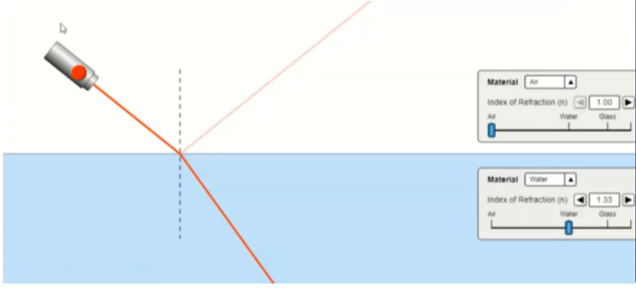


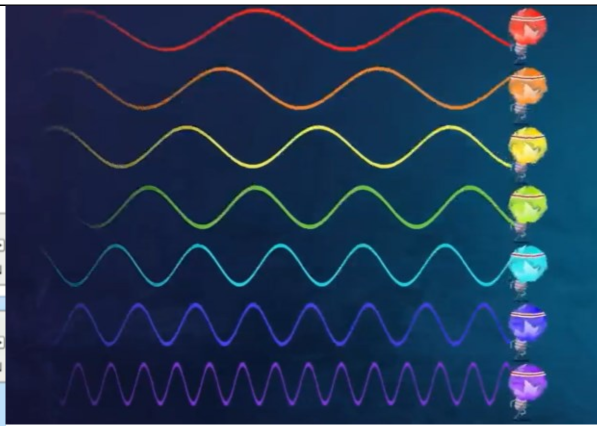


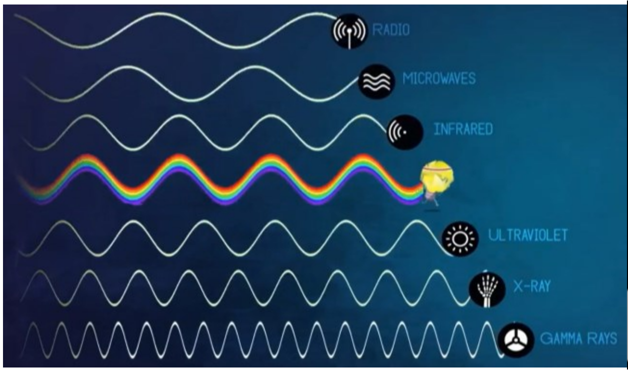


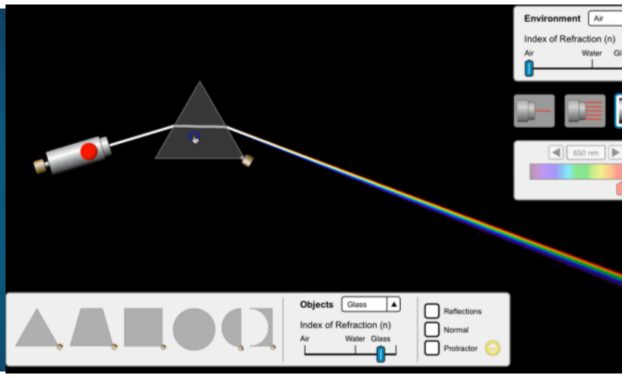


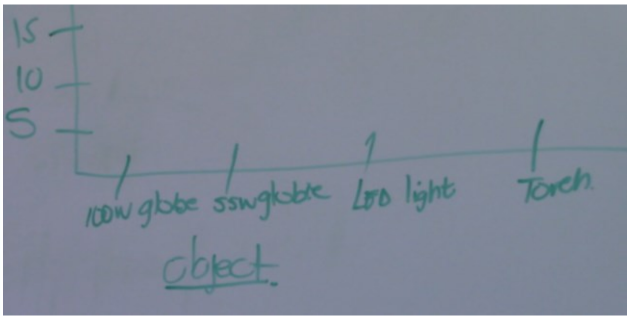




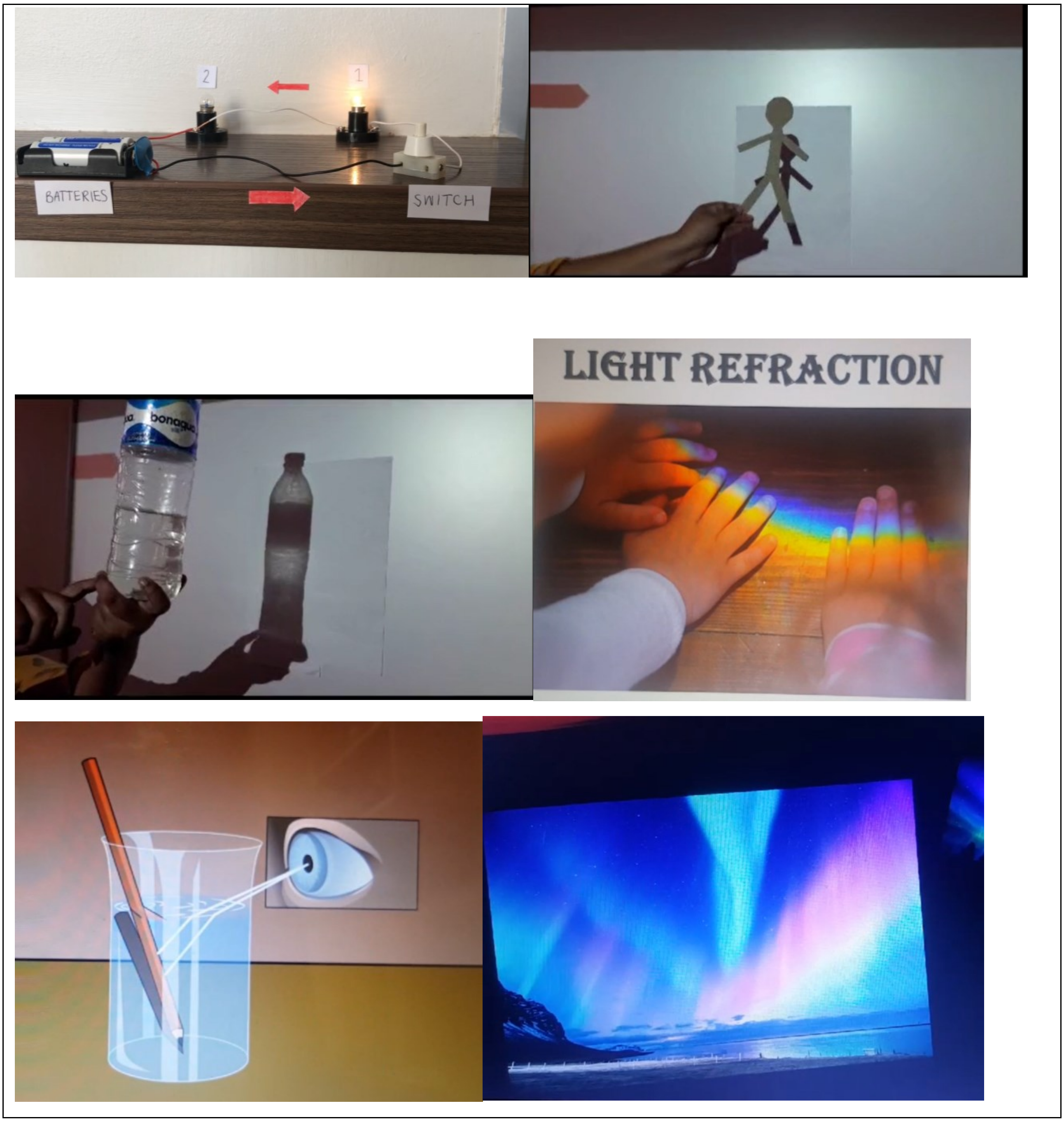


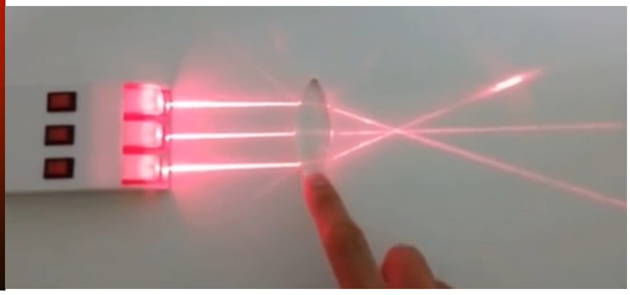
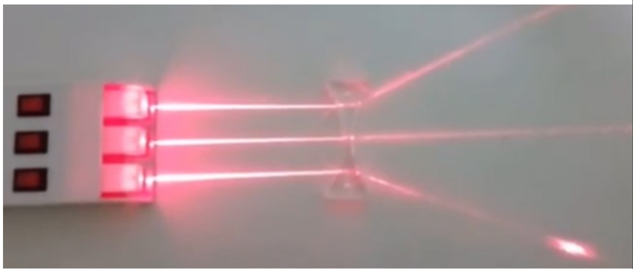


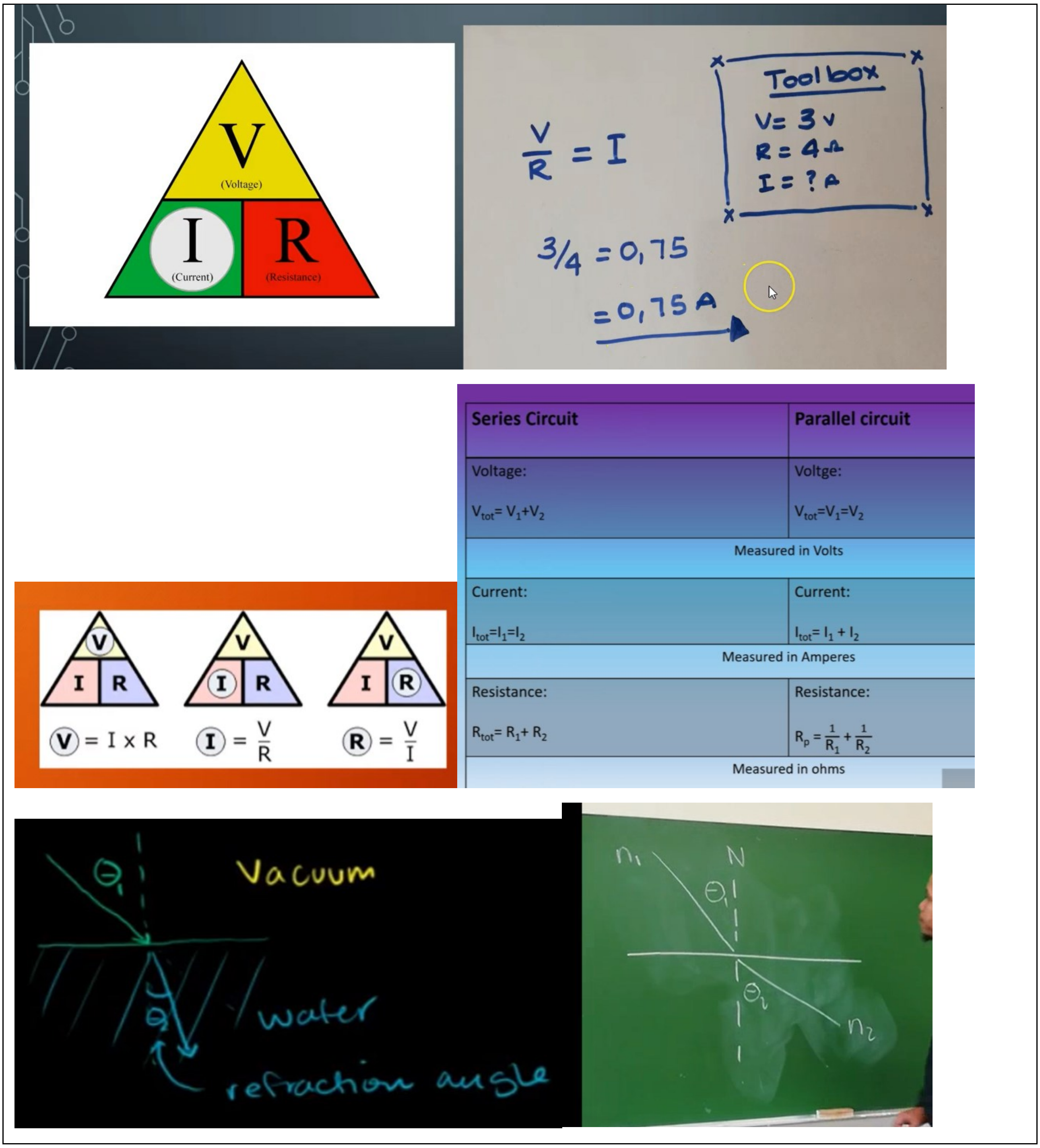


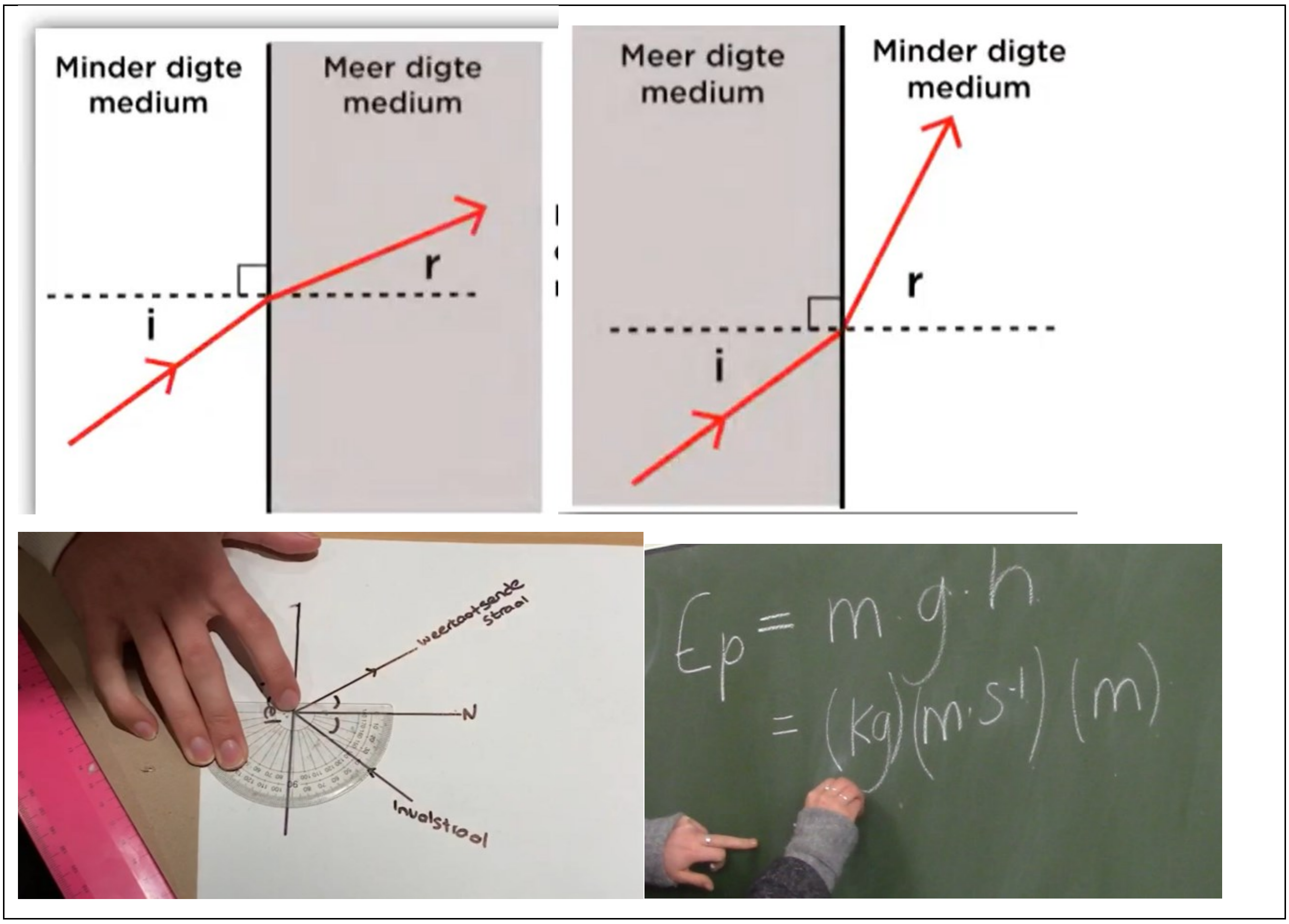


Experimental Representations


2
1
BATTERIES
SWITCH
bonaqua
LIGHT REFRACTION

   
Symbolic Representations


V
(Voltage)
I
(Current)
R
(Resistance)
V/R = I
Toolbox
V= 3 V
R = 4 Ω
I = ? A
3/4 = 0,75
= 0,75 A
Series Circuit
Parallel circuit
Voltage:
Vtot= V1+V2
Voltge:
Vtot=V1=V2
Measured in Volts
Current:
Itot=I1=I2
Current:
Itot= I1 + I2
Measured in Amperes
Resistance:
Rtot= R1+ R2
Resistance:
Rp = 1/R1 + 1/R2
Measured in ohms
V = I x R
I = V/R
R = V/I
Vacuum
water
refraction angle
n1
N
n2



The predominant modes found to be used in Physics for this study are thus Non-specialist Words, Graphical representations and Expert Words.

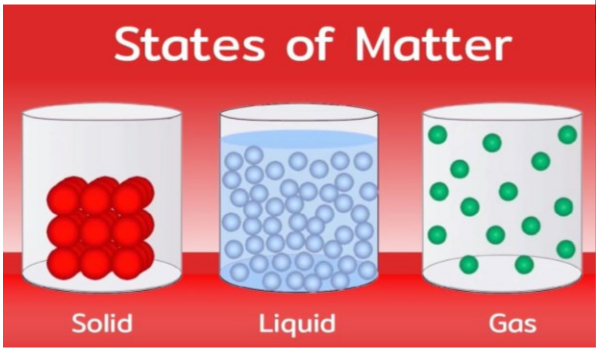
5.3.2 Different Modes of Representation Used in Chemistry

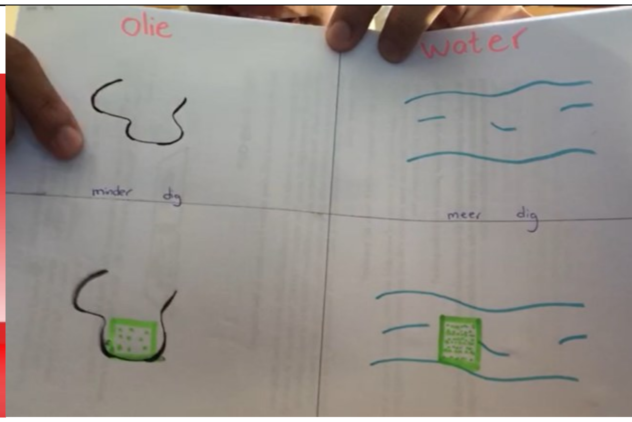
From Table 4.8 it is evident that none of the representational modes were not used at all in the analysed Chemistry lessons. One can also conclude that the modes that was used most prominent in Chemistry are Non-specialist Words (100%), Experimental representations (85,71%), and Expert Words (89,29%). While Graphical representations (58,33%) and Symbolic representations (55,95%) were showcasing average amounts of evidence of use during these lessons.

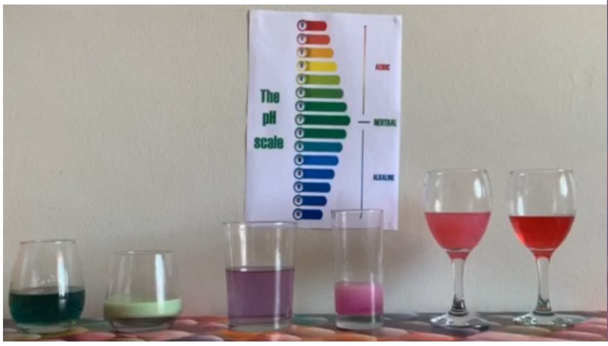
In Table 5.10 below examples of the representational modes used can be seen, excluding Non-specialist and Expert Words as this is seen as embedded in all the other representational modes and elaborated on in Section 5.6.

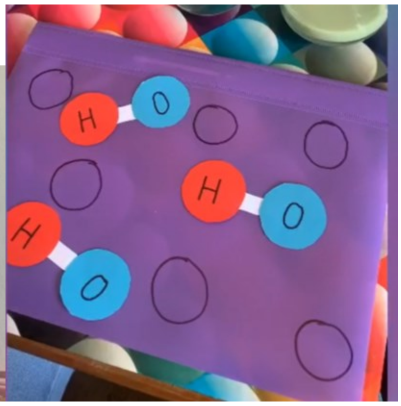
Table 5.10: Examples of the representations observed in the Chemistry lessons classified under the relevant representational mode

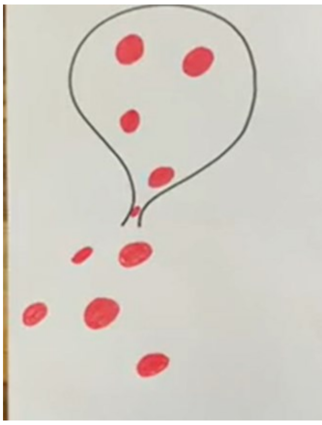
Graphical Representations

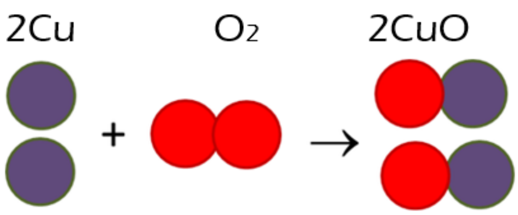


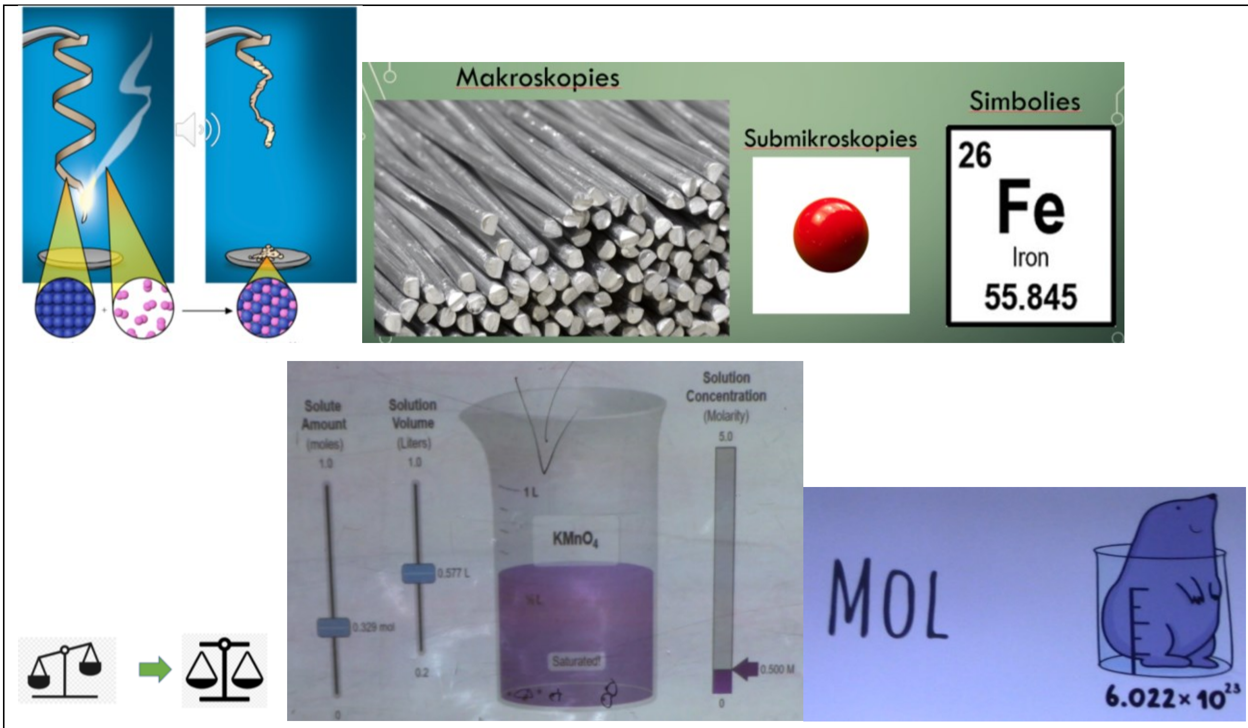




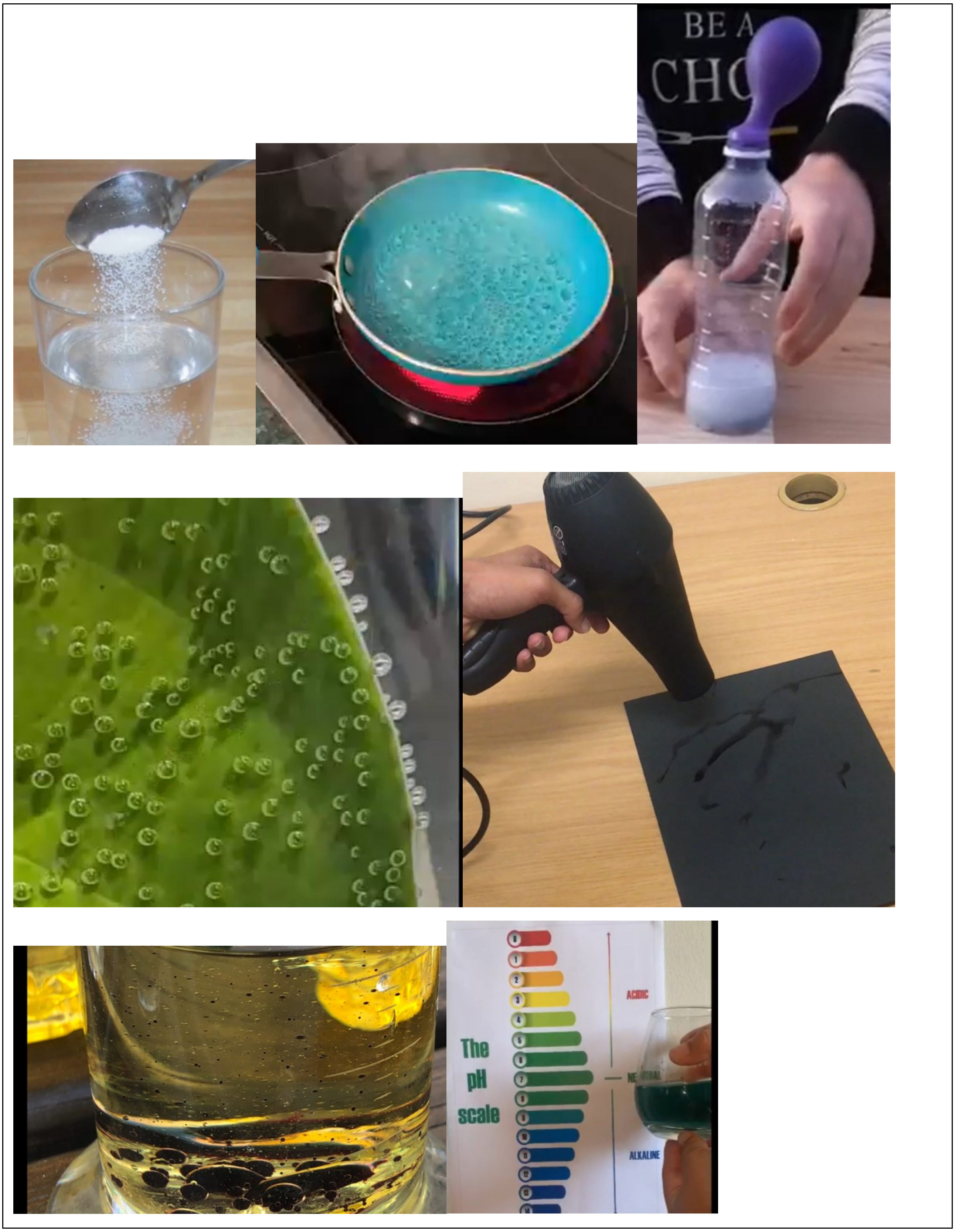


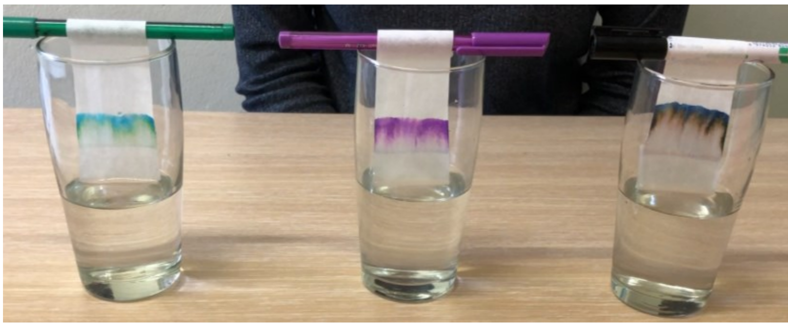


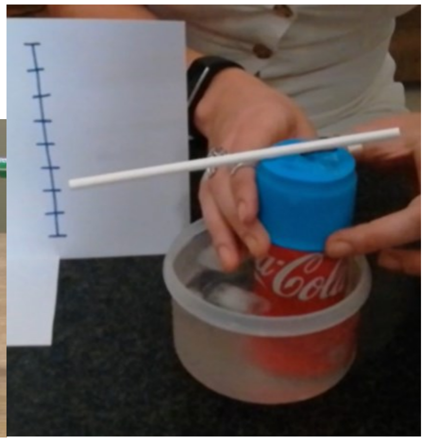


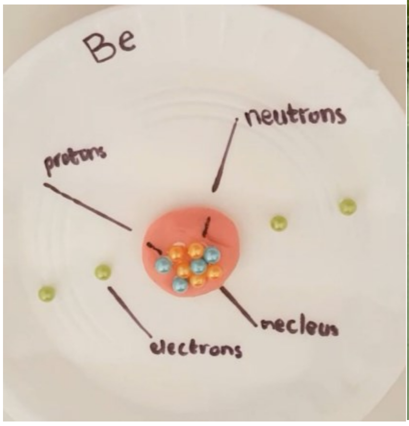


Experimental Representations


The
pH
scale
ACIDIC
ALKALINE

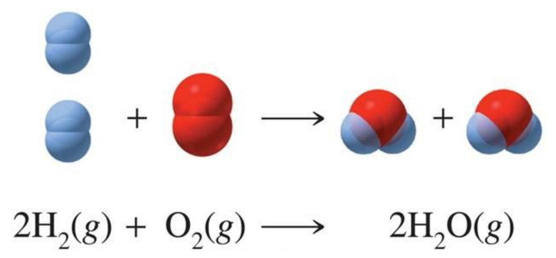


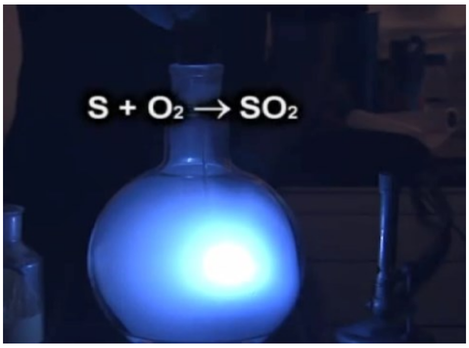


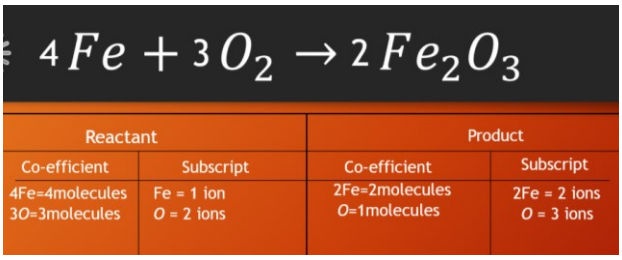

Be
neutrons
protons
electrons
necleus

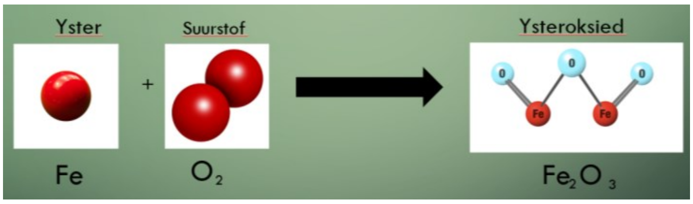
Symbolic Representations

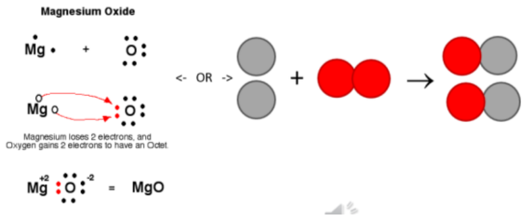
$NaHCO_3 + CH_3COOH \rightarrow CO_2 + H_2O + NaCH_3COO$

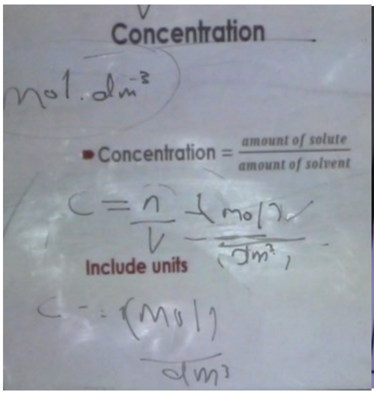


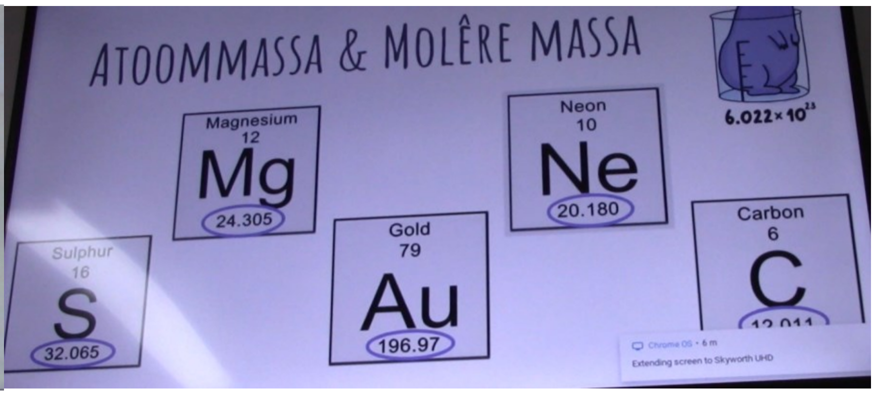


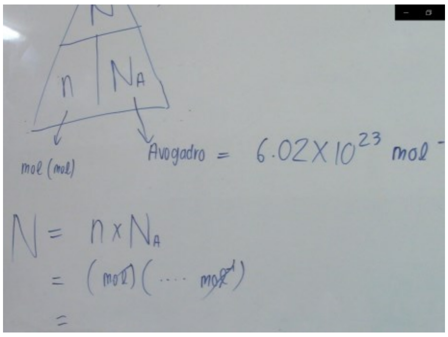












The predominant modes found to be used in Chemistry for this study are thus Non-specialist Words, Experimental representations and Expert Words.

5.3.3 Different Modes of Representation Used in Physics and Chemistry Combined

From Table 4.9 it is evident that none of the representational modes were not used at all in the analysed lessons for Physics and Chemistry combined. One can also conclude that the modes that was used most prominent in all the lessons are Non-specialist Words (98,80%) and Expert Words (90,42%). While Graphical representations (74,85%) and Experimental representations (80,24%) were found to be used in relatively high amounts during these lessons, it is evident that overall relatively very little evidence of the use of Symbolic representations (35,93%) could be found in the data.

This finding would make sense, since Symbolic representations was the least used (least observed) mode for both Physics and Chemistry, while Non-specialist Words was the most used (most observed) mode for both Physics and Chemistry.

Ainsworth and Newton (2014) found that it is easy for science teachers to name examples of and teach with multiple representation, however found that it was not easy for them to rationalise why certain representations are used. Ainsworth et al. (2014) also found that the modes most often used by these teachers were graphs, diagrams, animations and text. Cooper and Stowe (2018) note that even though teacher training endeavors do not expect PSSTs to be complete experts at the completion of their first qualification, the aim is for these PSSTs to develop more expert-like knowledge structures and thus their expertise. In the theoretical framework of this study a teacher's PCK is seen as transformative and thus the expertise will develop and increase over time. In the findings of this section, it is evident that these PSSTs mostly make use of MRs as part of their PCK, however the level at which these MRs are used is not evident from this discussion alone. I can however conclude that the use of Symbolic representations as part of the PSSTs expertise could be improved. Taber (2009) emphasised the importance of teachers' ability to use symbolic representations as experts, but acknowledges that it is very often found that students (in this case the PSSTs) may not understand the symbolism used in teaching science concepts. This finding could therefore potentially point to a general phenomenon that PSSTs are not sufficiently equipped to use symbolic representations and therefore do not make use of these in lesson presentations while still developing their PCK.

5.4 Representational Modes Used in Chemistry and Physics

This section aims to answer the following research sub-question:

b) Is there a statistically significant difference between pre-service science teachers' use of multiple representations as well as their level of representational competence and fluency in Physics and Chemistry?

5.4.1 Modes of Representation Used in Physics and Chemistry

The analysis points towards a statistically significant difference in the level of competence and fluency PSSTs exhibit for the same representational mode in Physics and Chemistry, while some results shows that there is no statistically significant difference between the level of competence and fluency PSSTs exhibit for the same representational mode in Physics and Chemistry. Below the findings are discussed and where a statistically significant difference was found, the biggest contributors to the statistical difference are identified and discussed.

OBSERVED RESULTS AND EXPECTED RESULTS THAT ARE NOT STATISTICALLY SIGNIFICANTLY DIFFERENT

From the chi-square test results obtained and set out in Table 4.10 one can see that the null-hypothesis was accepted for Experimental Representations (p=0.22), Non-specialist Words (p=0.44) and Expert Words (0.12) when comparing these modes for Chemistry and Physics. This conclusion is made because of the chi-square values being smaller than the critical value of 7.815 (df=3) and thus the probability values (p) were found to be greater than 0.05. Since the null-hypothesis was accepted, the alternative hypothesis is rejected. This means that there no difference and also no relationship between these representational modes for Chemistry and Physics.

It was found (from Figure 4.8 and Table 4.12) that the observed outcome levels of competence and fluency of the PSSTs in using Experimental Representations for Chemistry compared to Physics was not statistically different than what was expected.

It was found (from Figure 4.10 and Table 4.14) that the observed outcome levels of competence and fluency of the PSSTs in using Non-specialist Word Representations for Chemistry compared to Physics was not statistically different than what was expected.

It was found (from Figure 4.11 and Table 4.15) that the observed outcome levels of competence and fluency of the PSSTs in using Expert Word Representations for Chemistry compared to Physics was not statistically different than what was expected.

OBSERVED RESULTS AND EXPECTED RESULTS THAT ARE STATISTICALLY SIGNIFICANTLY DIFFERENT

From the chi-square test results obtained and set out in Table 4.10 one can see that the null-hypothesis was rejected for Graphical representations ($p < 0.05$) and Symbolic Representations ($p < 0.05$) when comparing these modes for Chemistry and Physics. This conclusion is made because of the chi-square values being bigger than the critical value of 7.815 (df=3) and thus the probability values (p) were found to be smaller than 0.05. Since the null-hypothesis was rejected, the alternative hypothesis is accepted. This means that there is a relationship between these representational modes for Chemistry and Physics.

It was found (from Figure 4.7 and Table 4.11) that the observed outcome levels of competence and fluency of the PSSTs in using Graphical Representations for Chemistry compared to Physics was statistically different than what was expected. In Table 4.11 it is evident that the biggest contributors to the chi-square value obtained, which was bigger than the critical value, are the no attempt codes (Code 0) and the high-level (Code 3) and thus these levels of competence and fluency is statistically different for Physics and Chemistry with regards to Graphical representations. In Figure 4.7 it is clear that of all the lessons presented, and coded in which no attempt was made at using Graphical representations, Chemistry lessons contributed 83% compared to only 17% by the Physics lessons presented. It is also clear that of all the lessons presented, and coded to have used Graphical representations at a high level of competence and fluency, Chemistry lessons contributed only 20% compared to the 80% by the Physics lessons presented.

It was found (from Figure 4.9 and Table 4.13) that the observed outcome levels of competence and fluency of the PSSTs in using Symbolic Representations for Chemistry compared to Physics was statistically different than what was expected. In Table 4.13 it is evident that the biggest contributors to the chi-square value obtained, which was bigger than the critical value, are the no attempt codes (Code 0) and the medium-level (Code 2) and thus these levels of competence and fluency is statistically different for Physics and Chemistry with regards to Symbolic representations. In Figure 4.9 it is clear that of all the lessons presented, and coded in which no attempt was made at using Symbolic representations, Chemistry lessons contributed only 35% compared to the 65% contributed by the Physics lessons presented. It is also clear that of all the lessons presented, and coded to have used Symbolic representations at a medium level of competence and fluency, Chemistry lessons contributed 86% compared to 14% by the Physics lessons presented.

The overall findings of this section can be presented as PSSTs showing similar levels of competence and fluency in using or not using Experimental representations, Non-specialist Words and Expert

Words when presenting Physics and Chemistry lessons. However, when Graphical representations were analysed it was found that a lot more PSSTs used these at a high level of competence and fluency when presenting Physics concepts compared to Chemistry concepts, while significantly more PSSTs did not make use of Graphical representations at all when presenting chemistry concepts. Where PSSTs use of Symbolic representations were analysed, significantly more of the participants did not make use of these representations when presenting Physics concepts, and a lot more participants used Symbolic representations at a medium level when presenting a Chemistry concept compared to Physics.

While this section looks at whether there is a statistically significant difference in the level of competence and fluency PSSTs exhibit for the same representational mode in Physics and Chemistry, the next section looks at whether there is a statistically significant difference in the level of competence and fluency PSSTs exhibit in general and across all representational modes in Physics and Chemistry.

5.4.2 Levels of Competence and Fluency at Which Modes of Representation Was Used in Physics and Chemistry

OBSERVED RESULTS AND EXPECTED RESULTS THAT ARE NOT STATISTICALLY SIGNIFICANTLY DIFFERENT

From the chi-square test results obtained and set out in Table 4.17 one can see that the null-hypothesis was accepted when comparing the levels of competence and fluency ($p=0.23$) for Chemistry and Physics. This conclusion is made because of the chi-square values being smaller than the critical value of 7.815 ($df=3$) and thus the probability value (p) was found to be bigger than 0.05. Since the null-hypothesis was accepted, the alternative hypothesis is rejected. This means that there is no relationship between the representational modes for Physics and Chemistry for the whole sample population.

It was found (from Figure 4.12 and Table 4.18) that the observed outcome levels of competence and fluency of the PSSTs for Chemistry compared to Physics was not statistically significantly different than what was expected. The overall findings of this section can be presented as PSSTs showing similar levels of competence and fluency across all representational modes combined when presenting Physics and Chemistry lessons.

Eilam, Poyas and Hashimshoni (2014) conducted a study and found that overall teachers proved low levels of competence in using MRs. Eilam et al. (2014, p. 62) also found that the words used to describe the assignment and the characteristics of the concept had a significant influence when teachers determine which representations to use in their teachings and state that "This mental link may lead teachers to generate or select a VR (visual representation) without deeply understanding the particular characteristics that make each VR efficient for representing a specific scenario". This links to the findings discussed in Section 5.2 of this study.

5.5 Integration across Different Modes of Representation

This section aims to answer the following research sub-question:

c) How do pre-service science teachers engage in translation activities (integration across different modes of representation) in order to explain a specific scientific concept?

5.5.1 Integration across Different Modes of Representation in Physics

McCollum et al. (2016) identifies experts from novices in science as those members of the community who can efficiently transform (translate) and coordinate (navigate) between MRs of phenomena. It is out of this that there is a need to look at fluency and translation between MRs explaining the same science concept (or parts thereof), since science teachers should be viewed as and be able to teach as experts, not as novices. During the secondary coding phase a total of 7 different coding combinations and in total 43 (out of the 83 lessons observed) of these coding combinations were obtained to indicate fluency between representational modes in Physics (as noted in Table 4.19). The different codes obtained was as follows:

- GENS: Graphical + Experimental + Non-Specialist Words
- GENSX: Graphical + Experimental + Non-Specialist Words + Expert Words
- ENSX: Experimental + Non-Specialist Words + Expert Words
- GESNSX: Graphical + Experimental + Symbolic + Non-Specialist Words + Expert Words
- GSNSX: Graphical + Symbolic + Non-Specialist Words + Expert Words
- GNSX: Graphical + Non-Specialist Words + Expert Words
- GSNS: Graphical + Symbolic + Non-Specialist Words

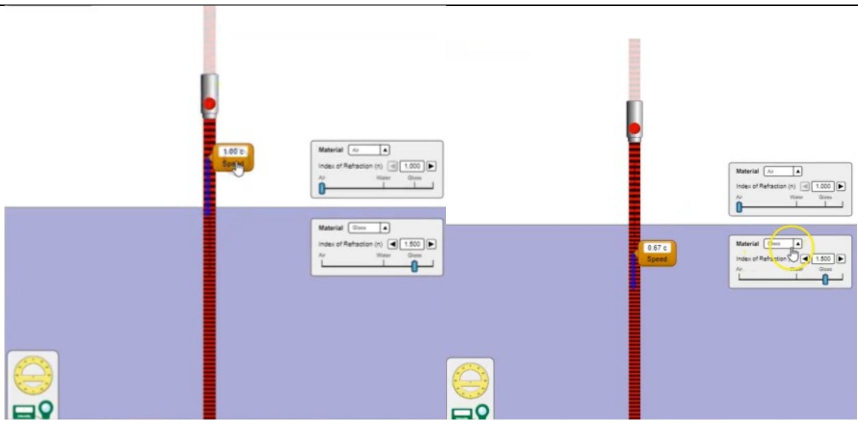
Out of the obtained codes, GNSX was observed most frequently (13 out of 43), GENSX second most frequently (11 out of 43) and GENS third most frequently (9 out of 43).

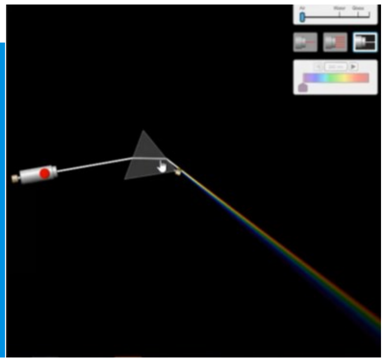
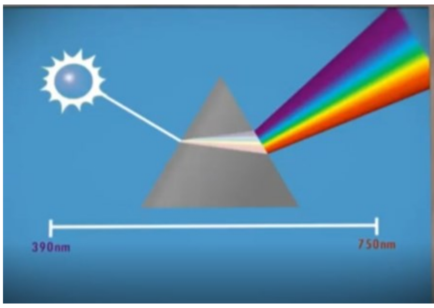
GNSX EXAMPLE (Unit 22: Group B)

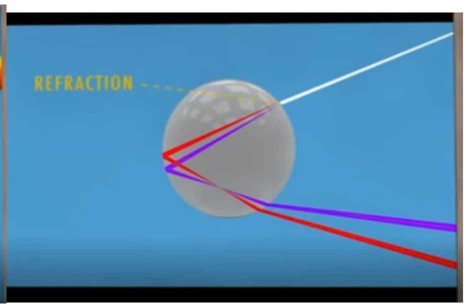
G	E	S	NS	X
3	0	0	3	3

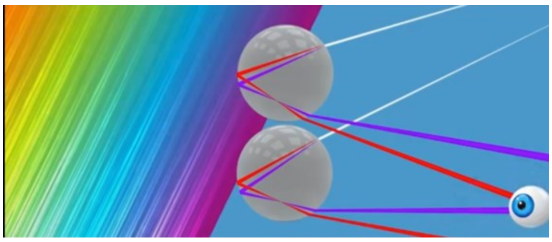
In the example discussed below there was evidence found for fluency between the Graphical representations and the Non-specialist – and Expert Words used to explain a lesson presented on Visible Light.

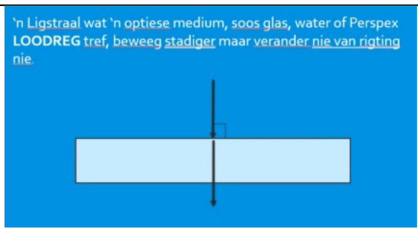
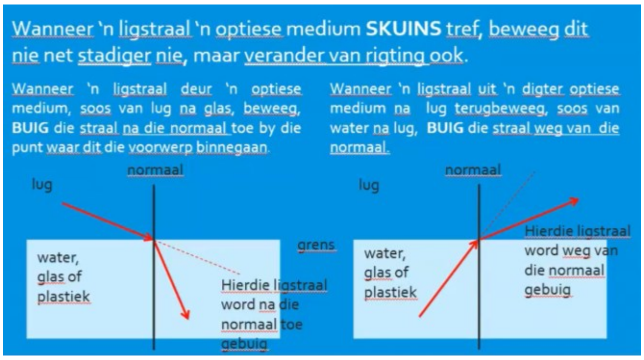
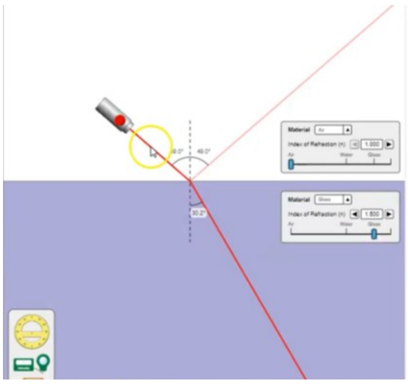
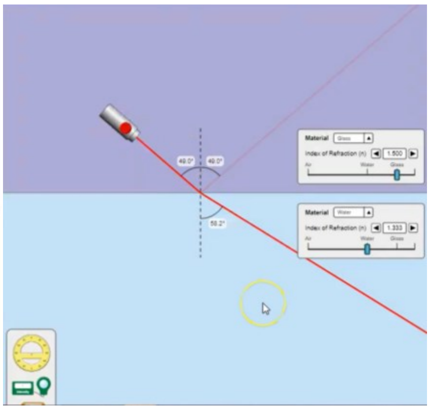
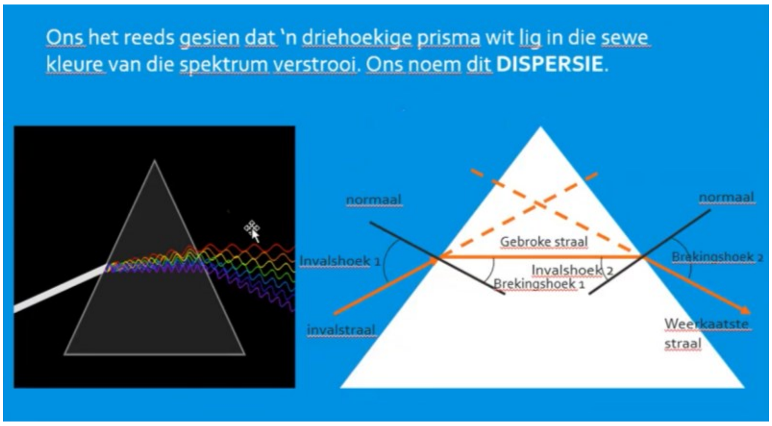
Table 5.11: Example of lesson analysis and coding for a lesson presented at a high level of competence and fluency with secondary code combination GNSX in Physics.

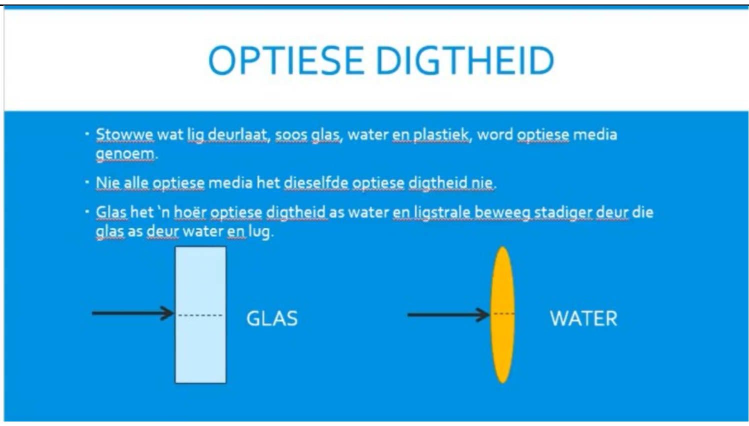
<table>
<tr><td colspan="2">Graphical Representations</td><td></td></tr>
<tr><td>Example</td><td>





</td><td>5.11a</td></tr>
</table>

	   	
Discussion	The PSST uses various graphical representations to explain and represent refraction of light. Explains what happens when light moves from optically less dense medium to optically more dense medium. Makes appropriate links through the use of language.	
Experimental Representations		
Example	NO EVIDENCE	5.11b
Symbolic Representations		
Example	NO EVIDENCE	5.11c

<table>
<tr><td colspan="2">Non-specialist Words</td><td></td></tr>
<tr><td>Example</td><td>*see all the screenshots in this table</td><td>5.11d</td></tr>
<tr><td>Discussion</td><td>PSST uses everyday language to link all the different representations and describes the phenomenon of refraction of light.</td><td></td></tr>
<tr><td colspan="2">Expert Words</td><td></td></tr>
<tr><td>Example</td><td>
</td><td>5.11e</td></tr>
<tr><td>Discussion</td><td>Appropriate use of science specific terms, mostly defined and always linked to the context and the graphical representations. PSST could have defined optical density a bit clearer.</td><td></td></tr>
</table>

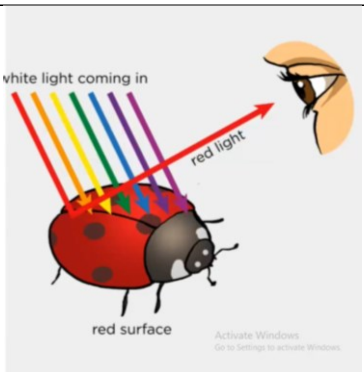
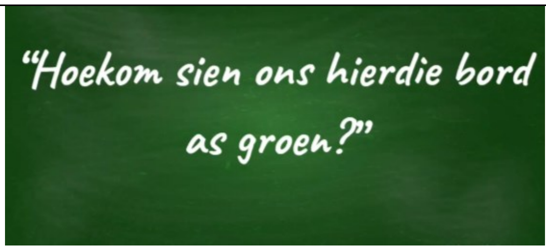
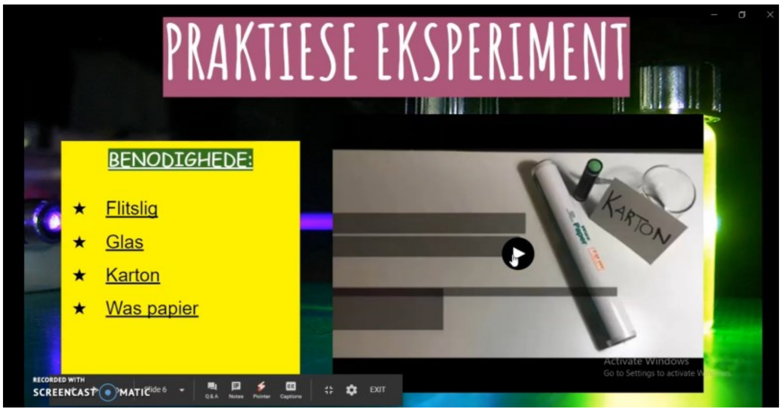
From the example above it is evident that even though there were high levels of fluency between Graphical representations and Non-specialist – and Expert Words, no evidence could be found for Experimental or Symbolic representations.

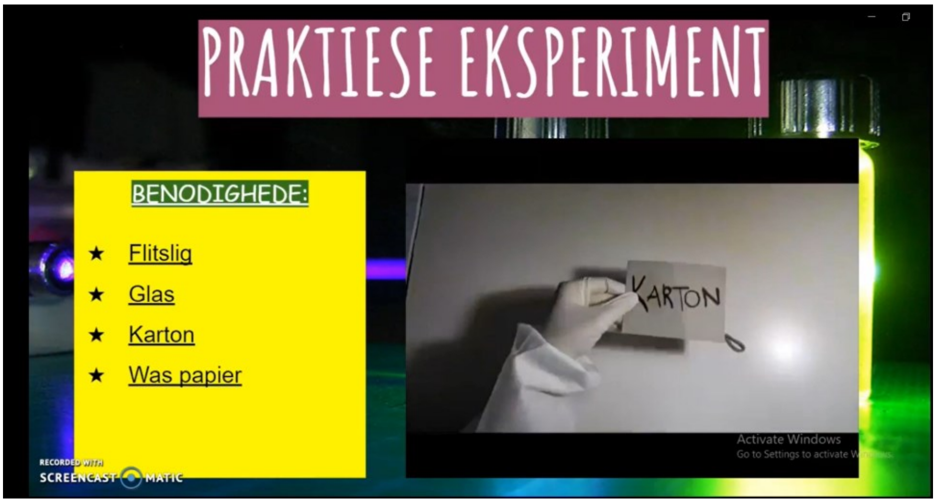
GENSX EXAMPLE (Unit 9: Group B)

G	E	S	NS	X
2	3	0	3	3

In the example discussed below there was evidence found for fluency between the Graphical representations, Experimental representations and the Non-specialist – and Expert Words used to explain a lesson presented on Visible Light.

Table 5.12: Example of lesson analysis and coding for a lesson presented at a high level of competence and fluency with secondary code combination GENSX in Physics.

Graphical Representations		
Example	 	5.12a
Discussion	The PSST could have used more graphical representations, however the representation above was linked to the experimental representations (5.12c) through the use of language. This is also linked to the question: “Why do we see the board as green?”	
Experimental Representations		
Example	   	5.12b


PRAKTIESE EKSPERIMENT
BENODIGHEDE:
★ Flitslig
★ Glas
★ Karton
★ Was papier
KARTON
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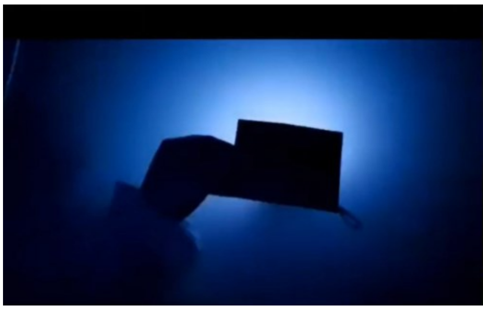
SCREENCAST-O-MATIC

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OM DIE ABSORPSIE VAN LIG TE VERSTAAN
Understanding Absorption of Light - Why do we see di...
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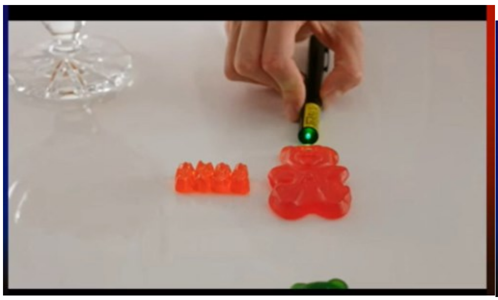
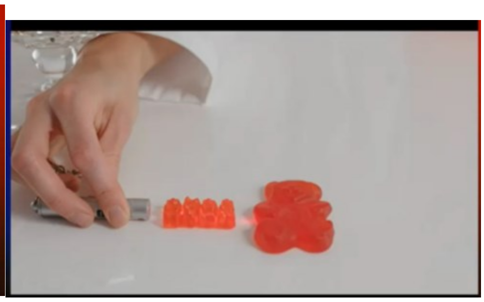
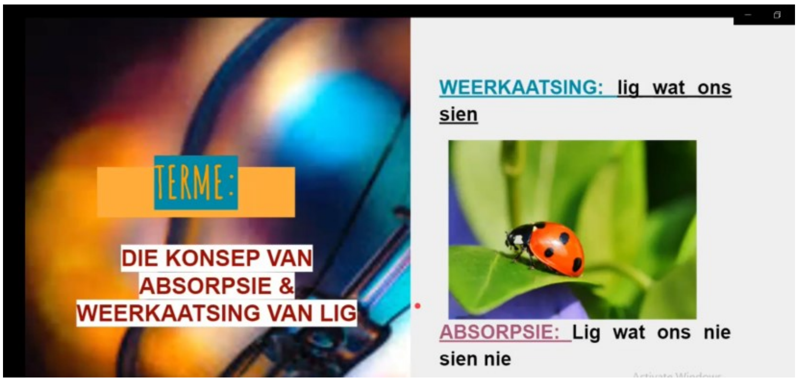




<table>
<tr><td>Discussion</td><td>The PSST demonstrates four different phenomena with light, each of these phenomena are defined (5.12e) and adequately explained and linked.</td><td></td></tr>
<tr><td colspan="2">Symbolic Representations</td><td></td></tr>
<tr><td>Example</td><td>NO EVIDENCE</td><td>5.12c</td></tr>
<tr><td colspan="2">Non-specialist Words</td><td></td></tr>
<tr><td>Example</td><td>The PSST mentions that white light is made up out of all the different colours of visible light. Give examples in everyday life such as glass, door etc.</td><td>5.12d</td></tr>
<tr><td>Discussion</td><td>PSST uses everyday language to link all the different representations and describes the phenomenon of refraction of light.</td><td></td></tr>
<tr><td colspan="2">Expert Words</td><td></td></tr>
<tr><td>Example</td><td>

</td><td>5.12e</td></tr>
<tr><td>Discussion</td><td>Science specific terms are correctly defined and referred t when explaining the experimental representations (5.12b).</td><td></td></tr>
</table>

From the example above it is evident that even though there were high levels of fluency between Graphical representations, Experimental representations and Non-specialist – and Expert Words, no evidence could be found for Symbolic representations.

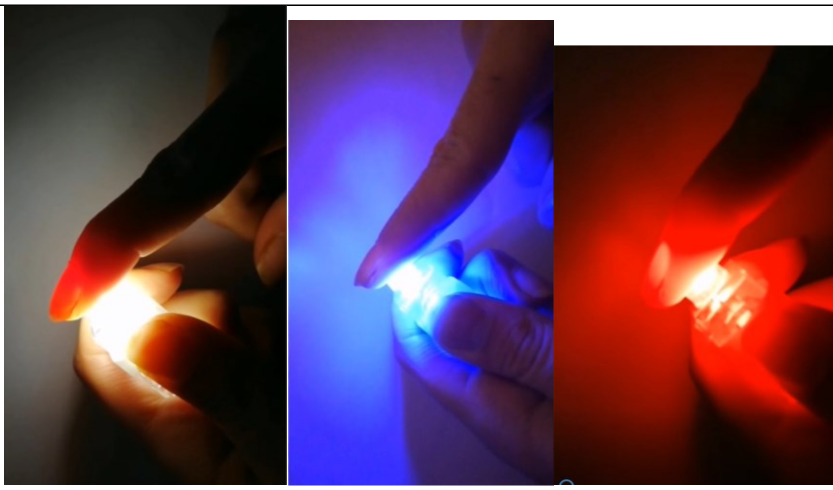
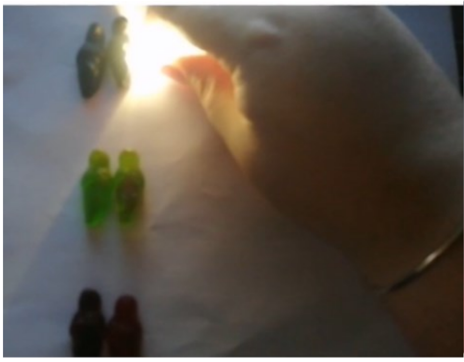
GENS EXAMPLE (Unit 30: Group B)

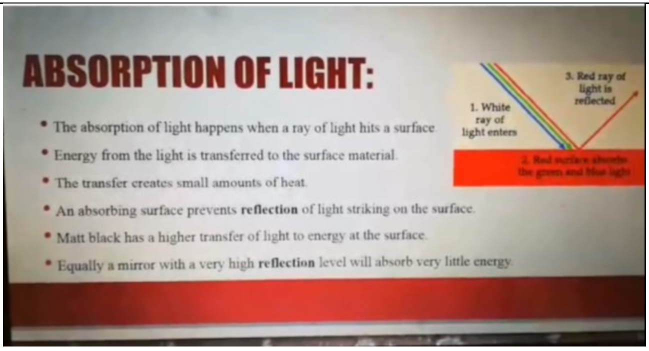
G	E	S	NS	X
2	3	0	3	1

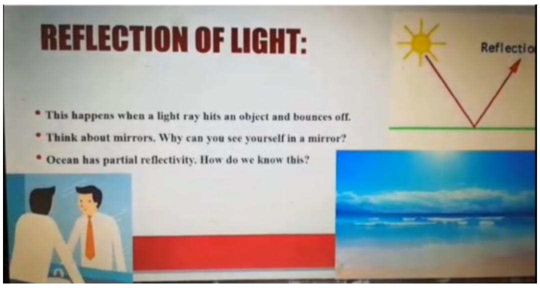
In the example discussed below there was evidence found for fluency between the Graphical representations, Experimental representations and the Non-specialist Words used to explain a lesson presented on Visible Light.

Table 5.13: Example of lesson analysis and coding for a lesson presented at a high level of competence and fluency with secondary code combination GENS in Physics.

Graphical Representations		
Example		5.13a
Discussion	Graphical and Experimental (5.13b) representations are adequately linked by means of everyday language to explain absorption and reflection of light.	
Experimental Representations		
Example		5.13b

	 Finger reflects red (from blood) when white light, and absorbs blue from blue light, reflects red from red light  	
Discussion	The PSST demonstrates that when shining white light on a finger, the red light is reflected and when shining white light on a black jelly baby it is completely absorbed. Also demonstrates that white light on green jelly baby reflects green and white light on red jelly baby reflects red. When shining a blue light on your finger, the blue light is absorbed, but when shining red light on your finger the red is reflected.	
Symbolic Representations		
Example	NO EVIDENCE	5.13c
Non-specialist Words		

<table>
<tr><td>Example</td><td>


</td><td>5.13d</td></tr>
<tr><td>Discussion</td><td>PSST uses everyday language to link all the different representations and describes the phenomenon of absorption and reflection of light.</td><td></td></tr>
<tr><td colspan="2">Expert Words</td><td></td></tr>
<tr><td>Example</td><td>NO FLUENCY
Science specific terms were not used often or defined in the context.</td><td>5.13e</td></tr>
</table>

From the example above it is evident that even though there was high levels of fluency between Graphical representations, Experimental representations and Non-specialist Words, no evidence could be found for Symbolic representations and the use of Expert Words took place at a very low level of competence and no fluency.

In the next section the fluency between representational modes in Chemistry lessons are presented.

5.5.2 Integration across Different Modes of Representation in Chemistry

During the secondary coding phase a total of 7 different coding combinations and in total 44 (out of the 84 lessons observed) of these coding combinations were obtained to indicate fluency between representational modes in Physics (as noted in Table 4.20). The different codes obtained was as follows:

- GENSX: Graphical + Experimental + Non-Specialist Words + Expert Words
- ENSX: Experimental + Non-Specialist Words + Expert Words
- GESNSX: Graphical + Experimental + Symbolic + Non-Specialist Words + Expert Words
- GSNSX: Graphical + Symbolic + Non-Specialist Words + Expert Words
- GSNS: Graphical + Symbolic + Non-Specialist Words

- ESNSX: Experimental + Symbolic + Non-Specialist Words + Expert Words
- SNSX: Symbolic + Non-Specialist Words + Expert Words

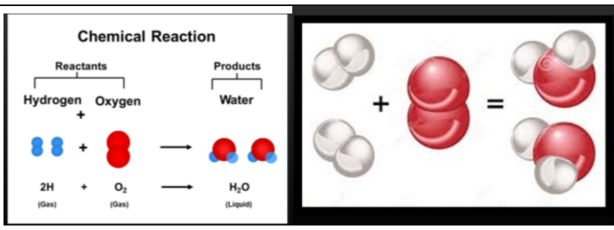
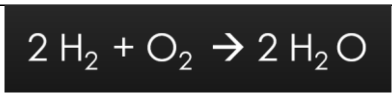
Out of the obtained codes, GSNSX was observed most frequently (14 out of 44), ENSX second most frequently (8 out of 44) and SNSX third most frequently (7 out of 44).

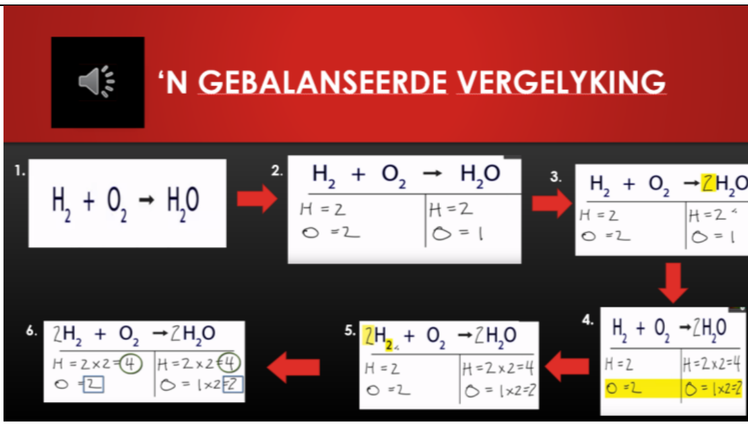
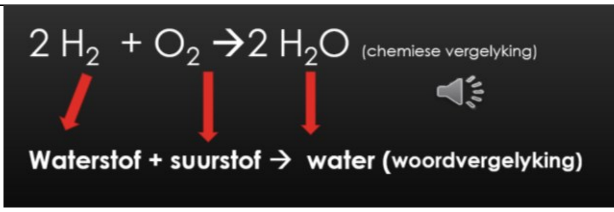
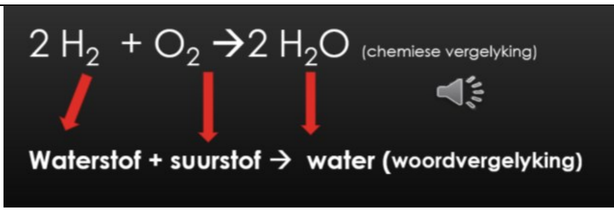
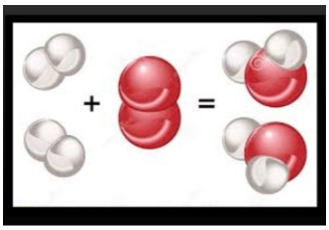
GSNSX EXAMPLE (Unit 11: Group D)

G	E	S	NS	X
3	0	3	3	2

In the example discussed below there was evidence found for fluency between the Graphical representations, Symbolic representations and the Non-specialist – and Expert Words used to explain a lesson presented on Chemical Reactions.

Table 5.14: Example of lesson analysis and coding for a lesson presented at a high level of competence and fluency with secondary code combination GSNSX in Chemistry.

Graphical Representations		
Example		5.14a
Discussion	The PSST mentions that humans won't survive without chemical reactions taking place and that there are millions of cells in your body. A chemical reaction is defined as when atoms rearrange, but no atoms are lost or gained during the reaction. Mentions that atoms are too small to see through a microscope. The graphical representation is correctly linked to the symbolic (5.14c) and word representations.	
Experimental Representations		
Example	NO EVIDENCE	5.14b
Symbolic Representations		
Example	 	5.14c

		
Discussion	The PSST explains what the symbolic representation means, links it to graphical (5.14a) and explains properly where the numbers come from. Names the coefficients and subscripts. Indicates that where there are no coefficient it represents one. Links to the definition of chemical reactions as to why and how reactions are balanced.	
Non-specialist Words		
Example		5.14d
Discussion	PSST uses everyday language to link all the different representations and describes the word equations and says this can be seen as a chemical language as it tells a chemical story.	
Expert Words		
Example	 	5.14e
Discussion	The PSST uses graphical and symbolic to generate the word equation for the reaction. Incorrectly writes an = sign instead of an arrow. Does not define and demonstrate subscript completely.	

From the example above it is evident that even though there was high levels of fluency between Graphical representations, Symbolic representations and Non-specialist – and Expert Words, no evidence could be found for Experimental representations.

ENSX EXAMPLE (Unit 12: Group D)

G	E	S	NS	X
0	3	1	3	3

In the example discussed below there was evidence found for fluency between the Experimental representations and the Non-specialist – and Expert Words used to explain a lesson presented on Chemical Reactions.

Table 5.15: Example of lesson analysis and coding for a lesson presented at a high level of competence and fluency with secondary code combination ENSX in Chemistry.

<table>
<tr><td colspan="2">Graphical Representations</td><td></td></tr>
<tr><td>Example</td><td>NO EVIDENCE</td><td>5.15a</td></tr>
<tr><td colspan="2">Experimental Representations</td><td></td></tr>
<tr><td>Example</td><td>

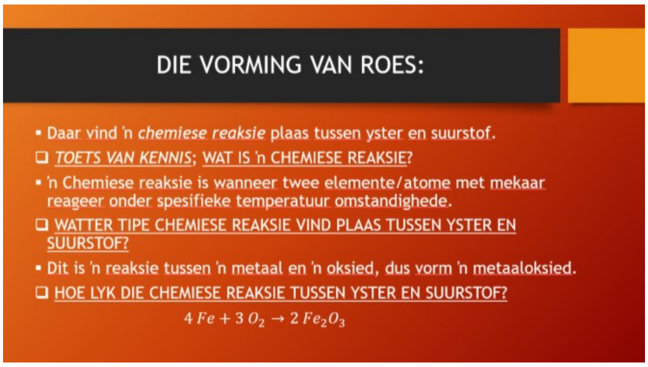

</td><td>5.15b</td></tr>
</table>

<table>
<tr><td></td><td>

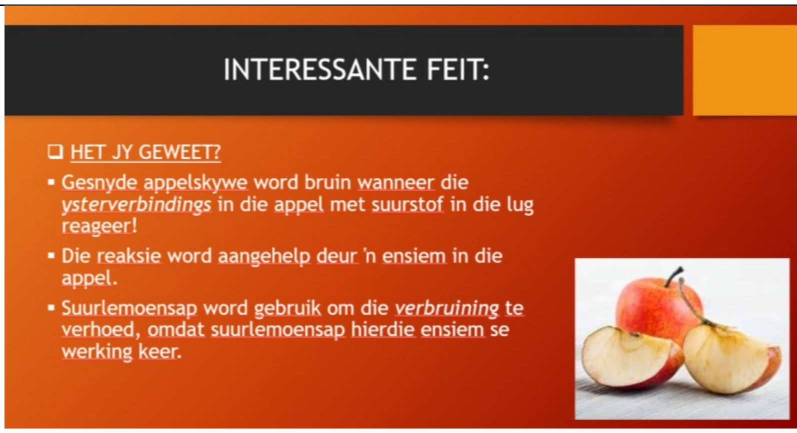

</td><td></td></tr>
<tr><td>Discussion</td><td>As an experimental representation the PSST discussed the prevention of rust and how to practically do it. This adequately linked to the use of language – written and spoken as the written text was read out loud in the recording.</td><td></td></tr>
<tr><td colspan="2">Symbolic Representations</td><td></td></tr>
<tr><td>Example</td><td>NO FLUENCY


HOE LYK DIE CHEMIESE REAKSIE TUSSEN YSTER EN SUURSTOF?
$4\,Fe + 3\,O_2 \rightarrow 2\,Fe_2O_3$
The phenomenon of rust is identified and the chemical equation is given, but not linked to the rest of the representations.</td><td>5.15c</td></tr>
<tr><td colspan="2">Non-specialist Words</td><td></td></tr>
</table>

<table>
<tr>
<td>Example</td>
<td>

</td>
<td></td>
<td>5.15d</td>
</tr>
</table>

		
Discussion	PSST uses everyday language to link the different representations and describes the formation of rust in words.	
Expert Words		
Example	Terms such as “atoms”, “molecules” and “chemical reactions” are used.	5.15e
Discussion	All science specific terms used at a high level of competence and fluency.	

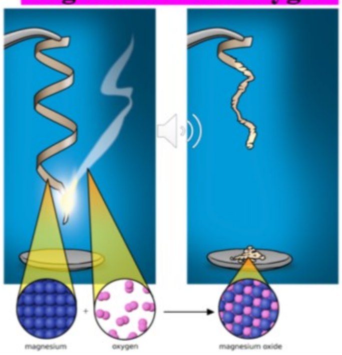
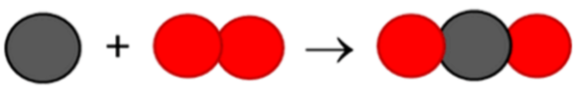
From the example above it is evident that even though there was high levels of fluency between Experimental representations and Non-specialist – and Expert Words, no evidence could be found for Graphical and the Symbolic representations used were not linked at all to the context of the lesson.

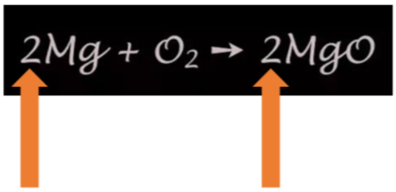
SNSX EXAMPLE (Unit 10: Group D)

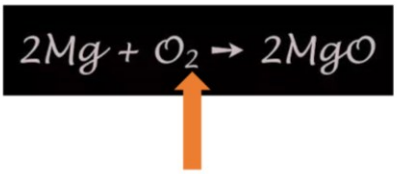
G	E	S	NS	X
1	1	3	3	2

In the example discussed below there was evidence found for fluency between the Symbolic representations and the Non-specialist – and Expert Words used to explain a lesson presented on Chemical Reactions.

Table 5.16: Example of lesson analysis and coding for a lesson presented at a high level of competence and fluency with secondary code combination SNSX in Chemistry.

Graphical Representations		
Example	NO FLUENCY **A submicroscopic representation of the reaction of magnesium with oxygen.**  Microscopic representation – refers to atoms. Blue is magnesium and pink is oxygen. Circle on the right shows combination of blue and pink atoms which shows that magnesium and oxygen combined to form magnesium oxide. However, not linked to any of the other representations as the diagram is not discussed at all. **Chemical equations and Atoms** There is no lose or gained atoms in chemical equations.  This diagram is used but not explained or linked to any other representations	5.16a
Experimental Representations		
Example	NO FLUENCY In graphical representation the reaction between two substances is mentioned but never elaborated on or linked.	5.16b
Symbolic Representations		
Example	The chemical equation is: $2Mg + O_2 \rightarrow 2MgO$	5.16c

<table>
<tr>
<td></td>
<td>
Coefficients in a chemical equation
• Coefficients in front of chemical formulae indicate the numbers of atoms or molecules of a specific type that take part in the reaction.


Subscripts in a chemical equation
• Subscripts inside chemical formulae indicate the number of atoms of a specific type in that particular compound.


A balanced equation
1. $Mg + O_2 \rightarrow MgO$
2. $Mg + O_2 \rightarrow 2MgO$
3. $2Mg + O_2 \rightarrow 2MgO$
</td>
<td></td>
</tr>
<tr>
<td>Discussion</td>
<td>Symbols are the element which are used in the equation. Does not elaborate on balanced equation at first, but then continues to say that in a balanced equation equal numbers of the same atoms are on opposite sides of reaction equations. (1 and 2 unbalanced; 3 balanced). The symbolic representations and everyday language usage is linked properly.</td>
<td></td>
</tr>
<tr>
<td colspan="2">Non-specialist Words</td>
<td></td>
</tr>
<tr>
<td>Example</td>
<td>No atoms lost or gained, only rearranged.
Blue is magnesium and pick is oxygen. Circle on the right shows combination of blue and pink atoms which shows that magnesium and oxygen combined to form magnesium oxide.</td>
<td>5.16d</td>
</tr>
</table>

Discussion	The PSST used adequate language (written and spoken) to explain the concept at hand, but only linking it to the symbolic representations, all the while using science specific terms (although only at a medium level of competence and fluency).	
Expert Words		
Example	The word equation is: **Magnesium + Oxygen ⟶ Magnesium Oxide**	5.16e
Discussion	When balancing the equation the PSST put number in front of the substances but does not mention the term “coefficients” at any point during the balancing. Only after the balancing is done. Terms such as “symbols”, “elements” and “chemical formulae” are used and linked to other representations.	

From the example above it is evident that even though there were high levels of fluency between Symbolic representations and Non-specialist – and Expert Words, the evidence that was found for Graphical or Experimental representations did not point towards high levels of competence and fluency.

Some of the overall findings of Section 5.5 can be summarised as follows: None of the most frequently observed code combinations for Physics (GNSX) and Chemistry (GSNSX) included Experimental representations. In each case only half of the participants showed representational fluency in Physics (43 out of 83) and Chemistry (44 out of 84). Lastly, only 4 out of 83 PSSTs showed high levels of representational fluency in all five representational modes in Physics and only 5 out of 84 PSSTs showed representational fluency in all five representational modes in Chemistry.

Cooper et al. (2018, p. 6057) describes expertise in line with a constructivist approach and say that “interconnected, contextualized, expert-like knowledge structures can be thought of as the product of careful cognitive construction that occurs in and is affected by one’s local context and community”. This points towards the importance of representational fluency in being a science teacher, the mediator of science concepts in the classroom community. Even though the PSSTs did show evidence of representational fluency, it was not a very impressive amount of the participants who did so, especially not the amount of participants who showed fluency in all five representational modes. One interesting aspect Cooper et al. (2018) also mention is that it is not necessarily true that an expert in a specific field or topic can teach others. The challenging role of the science teacher is exactly this: being an expert in the field and being able to teach the discipline to others. This takes us back to the importance of a strong PCK in the science classroom.

One of the findings in this study, namely that none of the most frequently observed code combinations for Physics (GNSX) and Chemistry (GSNSX) included Experimental representations corroborates the findings of a study conducted by Koopman (2017). The author found that a group of science teachers in South Africa focused on microscopic and sub-microscopic representations when teaching chemistry concepts, but did not (effectively) make use of real-life applications or macroscopic representations (ibid.). The author attributed this observation to how textbooks are structured around specific concepts and the extent to which the CAPS document could influence their PCK.

In the next section I will look at the results obtained in the study to determine how PSSTs use everyday literacy and scientific literacy when teaching science concepts.

5.6 The Use of Everyday Literacy vs Scientific Literacy

This section aims to answer the following research sub-question:

d) Is there a statistically significant difference in how pre-service science teachers use every day literacy compared to scientific literacy?

5.6.1 The Use of Everyday Literacy vs Scientific Literacy in Physics

OBSERVED RESULTS AND EXPECTED RESULTS THAT ARE STATISTICALLY SIGNIFICANTLY DIFFERENT

From the chi-square test results obtained and set out in Table 4.21 one can see that the null-hypothesis was rejected for Non-specialist Words and Expert Words ($p < 0.05$) when comparing these modes for Physics. This conclusion is made because of the chi-square value being bigger than the critical value of 7.815 (df=3) thus the probability values (p) were found to be smaller than 0.05. Since the null-hypothesis was rejected, the alternative hypothesis is accepted. This means that there is a relationship between the representational modes.

It was found (from Figure 4.13 and Table 4.22) that the observed outcome levels of competence and fluency of the PSSTs in using Everyday Literacy compared to Scientific Literacy in Physics was statistically different than what was expected. In Table 4.22 it is evident that the biggest contributors to the chi-square value obtained, which was bigger than the critical value, are the low-level codes (Code 1) and the high-level (Code 3) codes of competence and fluency for Everyday Literacy compared to Scientific Literacy in Physics. In Figure 4.13 it is clear that of all the lessons presented, and coded to have made a low-level competence and fluency attempt at using Everyday Literacy compared to Scientific Literacy in Physics, Non-specialist Words contributed only 23% compared to 77% contributed by the Expert Words used. It is also clear that of all the lessons presented, and coded to have made a high-level competence and fluency attempt at using Everyday Literacy compared to

Scientific Literacy in Physics, Non-specialist Words contributed 78% compared to only 22% contributed by the Expert Words used.

5.6.2 The Use of Everyday Literacy vs Scientific Literacy in Chemistry

OBSERVED RESULTS AND EXPECTED RESULTS THAT ARE STATISTICALLY SIGNIFICANTLY DIFFERENT

From the chi-square test results obtained and set out in Table 4.21 one can see that the null-hypothesis was rejected for Non-specialist Words and Expert Words ($p < 0.05$) when comparing these modes for Chemistry. This conclusion is made because of the chi-square value being bigger than the critical value of 7.815 (d=3) thus the probability values (p) were found to be smaller than 0.05. Since the null-hypothesis was rejected, the alternative hypothesis is accepted. This means that there is a relationship between these representational modes in Chemistry.

It was found (from Figure 4.14 and Table 4.23) that the observed outcome levels of competence and fluency of the PSSTs in using Everyday Literacy compared to Scientific Literacy in Chemistry was statistically different than what was expected. In Table 4.23 it is evident that the biggest contributors to the chi-square value obtained, which was bigger than the critical value, are the no attempt coding (Code 0), low-level codes (Code 1) and the high-level (Code 3) codes. In Figure 4.14 it is clear that of all the lessons presented, and coded to have made no attempt at using Everyday Literacy or Scientific Literacy in Chemistry, Non-specialist Words contributed 0% compared to 100% contributed by the Expert Words used. From Figure 4.14 one can also observe that of all the lessons presented, and coded to have made a low-level competence and fluency attempt at using Everyday Literacy compared to Scientific Literacy in Chemistry, Non-specialist Words contributed only 24% compared to 76% contributed by the Expert Words used. It is also clear that of all the lessons presented, and coded to have made a high-level competence and fluency attempt at using Everyday Literacy compared to Scientific Literacy in Chemistry, Non-specialist Words contributed 83% compared to only 17% contributed by the Expert Words used.

5.6.3 The Use of Everyday Literacy vs Scientific Literacy in Physics and Chemistry Combined

OBSERVED RESULTS AND EXPECTED RESULTS THAT ARE STATISTICALLY SIGNIFICANTLY DIFFERENT

From the chi-square test results obtained and set out in Table 4.21 one can see that the null-hypothesis was rejected for Non-specialist Words and Expert Words ($p < 0.05$) when comparing these modes for

Physics and Chemistry combined. This conclusion is made because of the chi-square value being bigger than the critical value of 7.815 (d=3) thus the probability values (p) were found to be smaller than 0.05. Since the null-hypothesis was rejected, the alternative hypothesis is accepted. This means that there is a relationship between the representational modes.

It was found (from Figure 4.15 and Table 4.24) that the observed outcome levels of competence and fluency of the PSSTs in using Everyday Literacy compared to Scientific Literacy in Physics and Chemistry combined was statistically different than what was expected. In Table 4.24 it is evident that the biggest contributors to the chi-square value obtained, which was bigger than the critical value, are the low-level codes (Code 1) and the high-level (Code 3) codes. In Figure 4.15 it is clear that of all the lessons presented, and coded to have made a low-level competence and fluency attempt at using Everyday Literacy compared to Scientific Literacy in Physics and Chemistry combined, Non-specialist Words contributed only 43% compared to 57% contributed by the Expert Words used. It is also clear that of all the lessons presented, and coded to have made a high-level competence and fluency attempt at using Everyday Literacy compared to Scientific Literacy in Physics and Chemistry combined, Non-specialist Words contributed 91% compared to only 9% contributed by the Expert Words used.

The overall findings of Section 5.6 points towards statistically significant differences in all areas of Non-specialist and Expert Words used. In the case of the Physics lessons presented, a lot more participants used Non-specialist Words at a high level of competence and fluency compared to Expert Words, while a significantly high amount of participants used Expert Words at a low level of competence and fluency. The findings for Chemistry reflected similar results, where significantly more PSSTs used Non-specialist Words at a high level of competence and fluency or did not use Expert Words at all. In general the findings for Physics and Chemistry lessons can be summarised as follows: Significantly more PSSTs used Non-specialist Words at a high level of competence and fluency, while significantly more PSSTs used Expert Words at a low level of competence and fluency. This finding is very important to note as it shows that the PSSTs are competent and fluent in using everyday literacy when teaching physics and chemistry, but that the use of scientific literacy during lessons is significantly absent or used at a low level of competence and fluency. The findings in this section are aligned with a study conducted on how elementary school science teachers label science concepts. In this study Glen and Dotger (2009) found that teachers who used science specific terms in their teachings, mostly did not define or link the terms to its origin or the concept under discussion, and conclude that science specific terms must be used as an interpretive system and not just a labelling system when teaching science.

5.7 Conclusion

The overall results for this study indicates that predominant modes used by PSSTs in Physics lesson presentations are Non-specialist Words, Graphical representations and Expert Words, while the predominant modes found to be used in Chemistry are Non-specialist Words, Experimental representations and Expert Words.

It was also found that there were no statistically significant differences for the level of competence and fluency between Physics and Chemistry for Experimental Representations, Non-specialist Words and Expert Words. There was however a statistically significant difference for the level of competence and fluency between Physics and Chemistry for Graphical representations and Symbolic Representations. This indicates some relationship between these representational modes – in Physics the Graphical representational mode is at a high-level whereas the Symbolic representational mode shows a high-level of competence and fluency in Chemistry.

This study found that there are no statistically significant differences in the levels of competence and fluency between Physics and Chemistry in general. This means that there is no relationship between representational modes for Physics and Chemistry as a whole.

In terms of the fluency and code combinations obtained from the secondary coding, out of all the codes obtained for Physics, GNSX was observed most frequently (13 out of 43), GENSX second most frequently (11 out of 43) and GENS third most frequently (9 out of 43). Out of the codes obtained for Chemistry, GSNSX was observed most frequently (14 out of 44), ENSX second most frequently (8 out of 44) and SNSX third most frequently (7 out of 44).

Lastly, the study found that there was a statistically significant difference for the level of competence and fluency between Non-Specialist Words and Expert Words for Physics, Chemistry and Physics and Chemistry combined. This means that there is a relationship between the representational modes – Non-Specialist Words dominate in Physics at 78% whereas 22% use Expert Words at a high-level. In Chemistry none of the PSSTs use Expert Words, and Non-Specialist Words also dominate whereas for Physics and Chemistry combine the pattern is much the same.

In conclusion the study finds that PSSTs mostly used Graphical Representations, Non-specialist – and Expert Words in Physics and Experimental Representations, Non-specialist – and Expert Words in Chemistry, but they did not regularly make use of Symbolic Representations when explaining science concepts. The common denominators between Physics and Chemistry lessons were the use of Non-specialist – and Expert Words, not looking at the competence and fluency level at which it was incorporated into the lesson. PSSTs explained science concepts at similar levels of competence and fluency for Physics and Chemistry when using Experimental Representations, Non-specialist Words and Expert Words, but at different levels when using Graphical representations and Symbolic Representations. This result could potentially be obtained due to the fact that the Physics lessons to be prepared on Electric circuits specifically instructed the PSSTs to use simulators (Graphical) and the Chemistry lessons on matter and materials to use the notes they received which included balanced chemical equations (Symbolic). PSSTs most frequently showed fluency between Graphical representations, Non-specialist Words and Expert Words when explaining Physics specific concepts, but showed fluency between Graphical representations, Symbolic representations, Non-specialist Words and Expert Words when explaining Chemistry concepts. What is interesting to see here is that even though PSSTs did not make use of Symbolic representations often when teaching Chemistry concepts, when they did use it they did so at a higher level of competence and fluency. Lastly, PSSTs did not necessarily use Non-specialist Words and Expert Words at similar levels of competence and fluency when explaining science concepts. Even if this was the case, for both Physics and Chemistry, those lessons which proved high levels of competence and fluency, the use of Non-specialist Words and Expert Words were both present and combined with other representational modes. This points towards the importance of language as part of a competent and fluent PCK.

In this chapter the discussion of the results obtained from the study, as guided by the main research question and sub-research questions, are summarised and presented. In the next chapter I will address these research questions shortly, present a few concluding remarks, address some relevant literature and make some recommendations for future research.

CHAPTER 6: CONCLUDING REMARKS AND IMPLICATIONS

6.1 Introduction

In this last chapter I will address each one of the research sub-questions and finally address the main research question this study aimed to investigate. I also provide recommendations for future research, especially in a South African science classroom. Lastly I will address how the results may potentially inform science teacher training endeavors and how this training may influence the PSSTs' PCK.

6.2 Addressing the Research Questions

The research sub-questions as set out in Chapter 1 were investigated as to inform the main research question on how pre-service science teachers use multiple representations as a pedagogical tool to explain science concepts during their lessons.

The first sub-question (a) focused on the different representational modes PSSTs explicitly and predominantly used to explain science specific questions. It was found that in Physics lessons specifically PSSTs decided to use Graphical Representations together with Non-specialist – and Expert Words, while in Chemistry they opted for Experimental Representations alongside Non-specialist – and Expert Words. Symbolic Representations were found to be used the least for both Physics and Chemistry lessons, even though it was still used in more than 3 times as many Chemistry lessons compared to Physics lessons.

The second sub-questions (b) looked at whether there is a statistical difference between PSSTs use of multiple representations as well as their level of representational competence and fluency in Physics and Chemistry. It was found that in general there was no statistically significant difference between PSSTs' levels of competence and fluency for Physics and Chemistry. This was found when the results were looked at across all representational modes combined. However, when looking at specific representational modes used in Physics compared to Chemistry, it was found that there was no statistically significant difference between PSSTs' levels of competence and fluency when using Experimental Representations, Non-specialist Words and Expert Words, but that there was a statistically significant difference between the PSSTs' levels of competence and fluency when using Graphical representations and Symbolic Representations.

The third sub-question (c) guided the study towards defining and investigating representational fluency amongst representational modes. It was found that in Physics translation mostly took place in the GNSX, GENSX and GENS representational mode combinations, while in Chemistry GSNSX, ENSX and SNSX representational mode combinations were used most often.

The last sub-question (d) looked at whether there is a statistically significant difference between PSSTs use of Non-specialist Words and Expert words when explaining Physics concepts, Chemistry concepts and Science concepts in general (Physics and Chemistry combined). It was found that there was a statistically significant difference for the level of competence and fluency between Non-Specialist Words and Expert Words for each one of the three settings.

This study can thus generally conclude in terms of how pre-service science teachers use multiple representations as a pedagogical tool to explain science concepts during their lessons, as follows:

PSSTs mostly use Graphical Representations, Non-specialist – and Expert Words in Physics and Experimental Representations, Non-specialist – and Expert Words in Chemistry, but they do not regularly make use of Symbolic Representations when explaining science concepts. PSSTs explain science concepts at similar levels of competence and fluency for Physics and Chemistry when using Experimental Representations, Non-specialist Words and Expert Words, but at different levels when using Graphical representations and Symbolic Representations. PSSTs most frequently showed fluency between Graphical representations, Non-specialist Words and Expert Words when explaining Physics specific concepts, but most frequently showed fluency between Graphical representations, Symbolic representations, Non-specialist Words and Expert Words when explaining Chemistry concepts. Lastly, PSSTs do not necessarily use Non-specialist Words and Expert Words at similar levels of competence and fluency when explaining science concepts.

This study can therefore specifically conclude in term of how pre-service science teachers use multiple representations as a pedagogical tool to explain science concepts during their lessons, as follows: The predominant modes found to be used in Physics were Non-specialist Words, Graphical representations and Expert Words. The predominant modes found to be used in Chemistry were Non-specialist Words, Experimental representations and Expert Words. None of the representational modes were not used at all in the analysed lessons for Physics and Chemistry. The modes that were used most prominently overall in all the lessons are Non-specialist Words and Expert Words. While Graphical representations and Experimental representation were found to be used in relatively high amounts during these lessons, it is evident that overall relatively very little evidence of the use of Symbolic representations could be found in the data. This finding would make sense, since Symbolic representations was the least used (least observed) mode for both Physics and Chemistry, while Non-specialist Words was the most used (most observed) mode for both Physics and Chemistry. An explanation for this may be due to the fact that the pre-service teachers' lessons could have been more focused on lower grades (Senior Phase) and not necessarily lessons containing Grades 11 and 12 (Further Education and Training Phase) content where symbolic representations are more prevalent. Normally when pre-service teachers go to schools for practice teaching they are only "allowed" to teach lower grades as they do not have the necessary experience to teach higher grades. PSSTs showed similar levels of competence and fluency in using or not using Experimental representations, Non-specialist Words and Expert Words when presenting Physics and Chemistry lessons. However, when Graphical representations were analysed it was found that a lot more PSSTs used these at a high level of competence and fluency when presenting Physics concepts compared to Chemistry concepts, while significantly more PSSTs did not make use of Graphical representations at all when presenting chemistry concepts. This observation could be attributed to the fact that PSSTs used PhET simulations more frequently while presenting physics topics compared to when teaching chemistry. Where PSSTs' use of Symbolic representations were analysed, significantly more of the participants did not make use of these representations when presenting Physics concepts, and a lot more participants used Symbolic representations at a medium level when presenting a Chemistry concept compared to Physics. Overall PSSTs showed similar levels of competence and fluency across all representational modes combined when presenting Physics and Chemistry lessons. None of the most frequently observed code combinations for Physics and Chemistry included Experimental representations. In each case only half of the participants showed representational fluency. Lastly, less than 5% of PSSTs showed high levels of representational fluency in all five representational modes in Physics and only about 6% PSSTs showed representational fluency in all five representational modes in Chemistry. The findings points towards statistically significant differences in Non-specialist and Expert Words used. Significantly more PSSTs used Non-specialist Words at a high level of competence and fluency, while significantly more PSSTs used Expert Words at a low level of competence and fluency.

The literature review, the findings of this study and my personal interpretation of the phenomenon under investigation informs the recommendations on future research and teacher training initiatives as set out in the rest of this chapter.

6.3 Recommendations for Future Research

My first recommendation for further studies in a South African context would be to investigate how an intervention between the two practical teaching phases the PSSTs have could impact the representational competence and fluency in presenting a science concept. This study combined the results for all of the lesson presentations, however there could be merit in distinguishing between the two teaching phases, namely the practice micro-teaching sessions and the practical experience at schools. In between the two practical experiences the PSSTs may be subject to intervention in the form of training in using all five representational modes when teaching science concepts, identifying the similarities and differences and choosing the most relevant modes for a specific topic. It would also be interesting to see how PSSTs approach the lesson presentations where no instruction is given with regards to the specific representational modes that must be used, compared to when explicit instructions are given. In my literature review a lot of emphasis was placed on the importance of language when teaching science and more specifically looking at everyday language and science specific language. From the results of this study it was seen that there a statistically significant difference in using Non-specialist Words and Expert Words at similar levels of competence and fluency when explaining science concepts. Investigating how language and choice of words used influence science instruction and PCK in a South African science classroom is definitely a domain of research that is necessary in South Africa. Lastly, it could be of interest to teacher trainers to investigate to what extent the CAPS curriculum for science may afford of constrain the PSSTs use of MRs, since many science teachers rely on this document to inform their PCK. This could potentially lead to revised curriculum approaches and thus adapted teacher training. This is also emphasised by Tippett (2011) saying that a lot is known about the importance of representational competence and fluency and *learning*, but relatively little research has been done on classroom *instruction* informed by representational competence and fluency and learning.

6.4 Science Teacher Training

Tippett (2011, p. 211) found that students', and in this case the PSSTs', competence in using MRs is more likely to improve when "...science is taught in a representation-rich learning environment and that environment should include explicit instruction about the functions, components, and conventions of representations". In Section 5.2 it was discussed how the assignments may have influenced the choice of representational modes the PSSTs choose when presenting the science concept, which in effect may have influenced the results obtained from this study. The implication is thus there for PSSTs to be explicitly trained to not just understand MRs, but also incorporate these as a part of their PCK. PSSTs should thus be aware of the pedagogical implications of teaching with MRs in science specifically. Out of the 167 PSST participants, only 4 participants showcased relatively high levels of representational competence and fluency across all 5 representational modes when teaching a Physics lesson, and only 5 participants did so when presenting a Chemistry lesson. These findings do not really indicate that the PSSTs showed adequate levels of competence and fluency when teaching science with the help of MRs, as the one must not be distinguished from the other when investigated as part of PSSTs' PCK.

6.5 Conclusion

In this chapter I briefly addressed each one of the research sub-questions and used these to finally conclude with how PSSTs used MRs as part of their PCK during lesson presentations. I proposed recommendations for future research and looked at the implications of the findings on science teacher training endeavors. I conclude this study with the following idea from Russel Edgerton as an afterthought - in reference to the work of Aristotle he concluded that teaching is the highest form of understanding (Edgerton, 1990).

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ADDENDA

ADDENDUM A: General and Specific Aims of the CAPS Curriculum

General aims of the South African Curriculum

(a) The National Curriculum Statement Grades R-12 gives expression to the knowledge, skills and values worth learning in South African schools. This curriculum aims to ensure that children acquire and apply knowledge and skills in ways that are meaningful to their own lives. In this regard, the curriculum promotes knowledge in local contexts, while being sensitive to global imperatives.

(b) The National Curriculum Statement Grades R-12 serves the purposes of:

equipping learners, irrespective of their socio-economic background, race, gender, physical ability or intellectual ability, with the knowledge, skills and values necessary for self-fulfilment, and meaningful participation in society as citizens of a free country;

providing access to higher education;

facilitating the transition of learners from education institutions to the workplace; and

providing employers with a sufficient profile of a learner's competences.

(c) The National Curriculum Statement Grades R-12 is based on the following principles:

Social transformation: ensuring that the educational imbalances of the past are redressed, and that equal educational opportunities are provided for all sections of the population;

Active and critical learning: encouraging an active and critical approach to learning, rather than rote and uncritical learning of given truths;

High knowledge and high skills: the minimum standards of knowledge and skills to be achieved at each grade are specified and set high, achievable standards in all subjects;

Progression: content and context of each grade shows progression from simple to complex;

Human rights, inclusivity, environmental and social justice: infusing the principles and practices of social and environmental justice and human rights as defined in the Constitution of the Republic of South Africa. The National Curriculum Statement Grades R-12 is sensitive to issues of diversity such as poverty, inequality, race, gender, language, age, disability and other factors;

Valuing indigenous knowledge systems: acknowledging the rich history and heritage of this country as important contributors to nurturing the values contained in the Constitution; and

Credibility, quality and efficiency: providing an education that is comparable in quality, breadth and depth to those of other countries.

(d) The National Curriculum Statement Grades R-12 aims to produce learners that are able to:

identify and solve problems and make decisions using critical and creative thinking;

work effectively as individuals and with others as members of a team;

organise and manage themselves and their activities responsibly and effectively;

collect, analyse, organise and critically evaluate information;

communicate effectively using visual, symbolic and/or language skills in various modes;

use science and technology effectively and critically showing responsibility towards the environment and the health of others; and

demonstrate an understanding of the world as a set of related systems by recognising that problem solving contexts do not exist in isolation.

(e) Inclusivity should become a central part of the organisation, planning and teaching at each school. This can only happen if all teachers have a sound understanding of how to recognise and address barriers to learning, and how to plan for diversity.

The key to managing inclusivity is ensuring that barriers are identified and addressed by all the relevant support structures within the school community, including teachers, District-Based Support Teams, Institutional-Level Support Teams, parents and Special Schools as Resource Centres. To address barriers in the classroom, teachers should use various curriculum differentiation strategies such as those included in the Department of Basic Education’s Guidelines for Inclusive Teaching and Learning (2010).

Specific Aims of Natural Sciences Curriculum (Senior Phase)

This curriculum aims to provide learners with opportunities to make sense of ideas they have about nature. It also encourages learners to ask questions that could lead to further research and investigation.

There are three specific aims in Natural Sciences

Specific Aim 1: 'Doing Science'

Learners should be able to complete investigations, analyse problems and use practical processes and skills in evaluating solutions.

Learners plan and do simple investigations and solve problems that need some practical ability. Attitudes and values underpin this ability. Respect for living things is an example – learners should not damage plants; if they examine small animals they should care for them and release them in the place where they found them.

Specific Aim 2: 'Knowing the subject content and making connections'

Learners should have a grasp of scientific, technological and environmental knowledge and be able to apply it in new contexts.

The main task of teaching is to build a framework of knowledge for learners and to help them make connections between the ideas and concepts in their minds – this is different to learners just knowing facts. When learners do an activity, questions and discussion must follow and relate to previously acquired knowledge and experience, and connections must be made.

Specific Aim 3: 'Understanding the uses of Science '

Learners should understand the uses of Natural Sciences and indigenous knowledge in society and the environment.

Science learnt at school should produce learners who understand that school science can be relevant to everyday life. Issues such as improving water quality, growing food without damaging the land and building energy-efficient houses are examples of applications. An appreciation of the history of scientific discoveries, and their relationship to indigenous knowledge and different world views, enriches our understanding of the connections between Science and Society.

Specific Aims of Physical Sciences Curriculum (Further Education and Training Phase)

The purpose of Physical Sciences is to make learners aware of their environment and to equip learners with investigating skills relating to physical and chemical phenomena, for example, lightning and solubility. Examples of some of the skills that are relevant for the study of Physical Sciences are classifying, communicating, measuring, designing an investigation, drawing and evaluating conclusions, formulating models, hypothesising, identifying and controlling variables, inferring, observing and comparing, interpreting, predicting, problem-solving and reflective skills.

Physical Sciences promotes knowledge and skills in scientific inquiry and problem solving; the construction and application of scientific and technological knowledge; an understanding of the nature of science and its relationships to technology, society and the environment.

Physical Sciences prepares learners for future learning, specialist learning, employment, citizenship, holistic development, socio-economic development, and environmental management. Learners choosing Physical Sciences as a subject in Grades 10-12, including those with barriers to learning, can have improved access to: academic courses in Higher Education; professional career paths related to applied science courses and vocational career paths. Physical Sciences plays an increasingly important role in the lives of all South Africans owing to their influence on scientific and technological development, which are necessary for the country’s economic growth and the social wellbeing of its people.

ADDENDUM B: Letter of Ethical Clearance Institutional Permission, Stellenbosch University

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INSTITUTIONAL PERMISSION:

AGREEMENT ON USE OF PERSONAL INFORMATION IN RESEARCH

Name of Researcher:	Christina Elizabeth Maree
Name of Research Project:	A study of pre-service science teachers' pedagogical use of multiple representations during lesson presentations
Service Desk ID:	IRPSD-1261
Date of Issue:	29 March 2019

The Researcher has received institutional permission to proceed with this project as stipulated in the institutional permission application and within the conditions set out in this agreement.

1 WHAT THIS AGREEMENT IS ABOUT	
What is POPI?	1.1 POPI is the Protection of Personal Information Act 4 of 2013. 1.2 POPI regulates the entire information life cycle from collection, through use and storage and even the destruction of personal information.
Why is this important to us?	1.3 Even though POPI is important, it is not the primary motivation for this agreement. The privacy of our students and employees are important to us. We want to ensure that no research project poses any risks to their privacy. 1.4 However, you are required to familiarise yourself with, and comply with POPI in its entirety.
What is considered to be personal information?	1.5 'Personal information' means information relating to an identifiable, living, individual or company, including, but not limited to: 1.5.1 information relating to the race, gender, sex, pregnancy, marital status, national, ethnic or social origin, colour, sexual orientation, age, physical or mental health, well-being, disability, religion, conscience, belief, culture, language and birth of the person; 1.5.2 information relating to the education or the medical, financial, criminal or

	employment history of the person; 1.5.3 any identifying number, symbol, e-mail address, physical address, telephone number, location information, online identifier or other particular assignment to the person; 1.5.4 the biometric information of the person; 1.5.5 the personal opinions, views or preferences of the person; 1.5.6 correspondence sent by the person that is implicitly or explicitly of a private or confidential nature or further correspondence that would reveal the contents of the original correspondence; 1.5.7 the views or opinions of another individual about the person; and 1.5.8 the name of the person if it appears with other personal information relating to the person or if the disclosure of the name itself would reveal information about the person.
Some personal information is more sensitive.	1.6 Some personal information is considered to be sensitive either because: 1.6.1 POPI has classified it as sensitive; 1.6.2 if the information is disclosed it can be used to defraud someone; or 1.6.3 the disclosure of the information will be embarrassing for the research subject. 1.7 The following personal information is considered particularly sensitive: 1.7.1 Religious or philosophical beliefs; 1.7.2 race or ethnic origin; 1.7.3 trade union membership; 1.7.4 political persuasion; 1.7.5 health and health related documentation such as medical scheme documentation; 1.7.6 sex life; 1.7.7 biometric information; 1.7.8 criminal behaviour; 1.7.9 personal information of children under the age of 18; 1.7.10 financial information such as banking details, details relating to financial

	products such as insurance, pension funds or other investments. 1.8 You may make use of this type of information, but must take extra care to ensure that you comply with the rest of the rules in this document.
2 COMMITMENT TO ETHICAL AND LEGAL RESEARCH PRACTICES	
You must commit to the use of ethical and legal research practices.	2.1 You must obtain ethical clearance before commencing with this study. 2.2 You commit to only employing ethical and legal research practices.
You must protect the privacy of your research subjects.	2.3 You undertake to protect the privacy of the research subjects throughout the project.
3 RESEARCH SUBJECT PARTICIPATION	
Personal information of identifiable research subjects must not be used without their consent.	3.1 Unless you have obtained a specific exemption for your research project, consent must be obtained in writing from the research subject, before their personal information is gathered.
Research subjects must be able to withdraw from the research project.	3.2 Research subjects must always be able to withdraw from the research project (without any negative consequences) and to insist that you destroy their personal information.
Consent must be specific and informed.	3.3 Unless you have obtained a specific exemption for your research project, the consent must be specific and informed. Before giving consent, the research subject must be informed in writing of: 3.3.1 The purpose of the research, 3.3.2 what personal information about them will be collected (particularly sensitive personal information), 3.3.3 how the personal information will be collected (if not directly from them), 3.3.4 the specific purposes for which the personal information will be used, 3.3.5 what participation will entail (i.e. what the research subject will have to do), 3.3.6 whether the supply of the personal information is voluntary or mandatory for purposes of the research project,

	3.3.7 who the personal information will be shared with, 3.3.8 how the personal information will be published, 3.3.9 the risks to participation (if any), 3.3.10 their rights to access, correct or object to the use of their personal information, 3.3.11 their right to withdraw from the research project, and 3.3.12 how these rights can be exercised.
Consent must be voluntary.	3.4 Participation in the research project must always be voluntary. You must never pressure or coerce research subjects into participating and persons who choose not to participate must not be penalised.
Using the personal information of children?	3.5 A child is anybody under the age of 18. 3.6 Unless you have obtained a specific exemption in writing for your research project, you must obtain 3.6.1 the consent of the child's parent or guardian, and 3.6.2 if the child is over the age of 7, the assent of the child, before collecting the child's information.
Research subjects have a right to access.	3.7 Research subjects have the right to access their personal information, obtain confirmation of what information is in your possession and who had access to the information. It is strongly recommended that you keep detailed records of access to the information.
Research subjects have a right to object.	3.8 Research subjects have the right to object to the use of their personal information. 3.9 Once they have objected, you are not permitted to use the personal information until the dispute has been resolved.
4 COLLECTING PERSONAL INFORMATION	
Only collect what is necessary.	4.1 You must not collect unnecessary or irrelevant personal information from research subjects.
Only collect accurate personal information.	4.2 You have an obligation to ensure that the personal information you collect is accurate. Particularly when you are collecting it from a source other than the

	research subject. 4.3 If you have any reason to doubt the quality of the personal information you must verify or validate the personal information before you use it.
5 USING PERSONAL INFORMATION	
Only use the personal information for the purpose for which you collected it.	5.1 Only use the personal information for the purpose for which you collected it. 5.2 If your research project requires you to use the personal information for a materially different purpose than the one communicated to the research subject, you must inform the research subjects and Stellenbosch University of this and give participants the option to withdraw from the research project.
Be careful when you share personal information.	5.3 Never share personal information with third parties without making sure that they will also follow these rules. 5.4 Always conclude a non-disclosure agreement with the third parties. 5.5 Ensure that you transfer the personal information securely.
Personal information must be anonymous whenever possible.	5.6 If the research subject's identity is not relevant for the aims of the research project, the personal information must not be identifiable. In other words, the personal information must be anonymous (de-identified).
Pseudonyms must be used whenever possible.	5.7 If the research subject's identity is relevant for the aims of the research project or is required to co-ordinate, for example, interviews, names and other identifiers such as ID or student numbers must be collected and stored separately from the rest of the research data and research publications. In other words, only you must be able to identify the research subject.
Publication of research	5.8 The identity of your research subjects should not be revealed in any publication. 5.9 In the event that your research project requires that the identity of your research subjects must be revealed, you must apply for an exemption from this rule.
6 SECURING PERSONAL INFORMATION	
You are responsible for the confidentiality and security of the personal information	6.1 Information must always be handled in the strictest confidence. 6.2 You must ensure the integrity and security of the information in your possession or under your control by taking appropriate and reasonable technical and organisational measures to prevent:

	6.2.1 Loss of, damage to or unauthorised destruction of information; and 6.2.2 unlawful access to or processing of information. 6.3 This means that you must take reasonable measures to: 6.3.1 Identify all reasonably foreseeable internal and external risks to personal information in your possession or under your control; 6.3.2 establish and maintain appropriate safeguards against the risks identified; 6.3.3 regularly verify that the safeguards are effectively implemented; and 6.3.4 ensure that the safeguards are continually updated in response to new risks or deficiencies in previously implemented safeguards.
Sensitive personal information requires extra care.	6.4 You will be expected to implement additional controls in order to secure sensitive personal information.
Are you sending any personal information overseas?	6.5 If you are sending personal information overseas, you have to make sure that: 6.5.1 The information will be protected by the laws of that country; 6.5.2 the company or institution to who you are sending have agreed to keep the information confidential, secure and to not use it for any other purpose; or 6.5.3 get the specific and informed consent of the research subject to send the information to a country which does not have data protection laws.
Be careful when you use cloud storage.	6.6 Be careful when storing personal information in a cloud. Many clouds are hosted on servers outside of South Africa in countries that do not protect personal information to the same extent as South Africa. The primary example of this is the United States. 6.7 It is strongly recommended that you use hosting companies who house their servers in South Africa. 6.8 If this is not possible, you must ensure that the hosting company agrees to protect the personal information to the same extent as South Africa.
7 RETENTION AND DESTRUCTION OF PERSONAL INFORMATION	
You are not entitled to retain personal information when you no longer need it for the purposes	7.1 Personal information must not be retained beyond the purpose of the research project, unless you have a legal or other justification for retaining the information.

of the research project.	
If personal information is retained, you must make sure it remains confidential.	7.2 If you do need to retain the personal information, you must assess whether: 7.2.1 The records can be de-identified; and/or whether 7.2.2 you have to keep all the personal information. 7.3 You must ensure that the personal information which you retain remains confidential, secure and is only used for the purposes for which it was collected.
8 INFORMATION BREACH PROCEDURE	
In the event of an information breach you must notify us immediately.	8.1 If there are reasonable grounds to believe that the personal information in your possession or under your control has been accessed by any unauthorised person or has been disclosed, you must notify us immediately. 8.2 We will notify the research subjects in order to enable them to take measures to contain the impact of the breach.
This is the procedure you must follow.	8.3 You must follow the following procedure: 8.3.1 Contact the Division for Institutional Research and Planning at 021 808 9385 and permission@sun.ac.za; 8.3.2 you will then be required to complete the information breach report form which is attached as Annexure A. 8.4 You are required to inform us of a information breach within 24 hours. Ensure that you have access to the required information.
9 MONITORING	
You may be audited.	9.1 We reserve the right to audit your research practices to assess whether you are complying with this agreement. 9.2 You are required to give your full co-operation during the auditing process. 9.3 We may also request to review: 9.3.1 Forms (or other information gathering methods) and notifications to research subjects, as referred to in clause 3; 9.3.2 non-disclosure agreements with third parties with whom the personal information is being shared, as referred to in clause 5.4;

	9.3.3 agreements with foreign companies or institutes with whom the personal information is being shared, as referred to in clause 6.5.
10 CHANGES TO RESEARCH	
You need to notify us if any aspect of your collection or use of personal information changes.	10.1 You must notify us in writing if any aspect of your collection or use of personal information changes (e.g. such as your research methodology, recruitment strategy or the purpose for which you use the research). 10.2 We may review and require amendments to the proposed changes to ensure compliance with this agreement. 10.3 The notification must be sent to permission@sun.ac.za.
11 CONSEQUENCES OF BREACH	
What are the consequences of breaching this agreement?	11.1 If you do not comply with this agreement, we may take disciplinary action or report such a breach to your home institute. 11.2 You may be found guilty of research misconduct and may be censured in accordance with Stellenbosch University or your home institute's disciplinary code.
You may have to compensate us in the event of any legal action.	11.3 Non-compliance with this agreement could also lead to claims against Stellenbosch University in terms of POPI and/or other laws. 11.4 Unless you are employed by or studying at Stellenbosch University, you indemnify Stellenbosch University against any claims (including all legal fees) from research subjects or any regulatory authority which are the result of your research project. You may also be held liable for the harm to our reputation should there be an information breach as a result of your non-compliance with this agreement.
12 CONTACT US	
Please contact us if you have any questions.	Should you have any questions relating to this agreement you should contact permission@sun.ac.za.

Annexure 'A'

Instruction:

Please send this Notice to permission@sun.ac.za. If you have any difficulty completing the Notice, please contact the Division for Institutional Research and Planning at 021 808 9385. You must confirm that the Notice was received.

NOTIFICATION OF INFORMATION BREACH

Name of Researcher: ______________________________

Name of Research Project: ______________________________

Service Desk ID: ______________________________

A security breach happens when you know (or you **reasonably believe**) that there has been:

(a) loss of Personal Information ("PI")
(b) damage to PI
(c) unauthorised destruction of PI
(d) unauthorised access to PI
(e) unauthorised processing of PI

Date and time of security breach:	
Brief description of the security breach (what was lost and how). Please identify the equipment, software and/or physical premises and whether it is by hacking, lost device, public disclosure (email), theft or other means:	
Name of the person/s responsible for the security breach (if known):	
Is the security breach ongoing?	
Describe the steps taken to contain the security breach:	
What steps are being taken to investigate the cause of breach?	

ADDENDUM C: Letter of Ethical Clearance Western Cape Education Department

Western Cape Government
Education

Directorate: Research

Audrey.wyngaard@westerncape.gov.za
tel: +27 021 467 9272
Fax: 0865902282
Private Bag x9114, Cape Town, 8000
wced.wcape.gov.za

REFERENCE: 20190313-2823
ENQUIRIES: Dr A T Wyngaard

Ms Christina Maree
Department of Curriculum Studies
Faculty of Education
Stellenbosch University
Private Bag X1
Matieland
7602

Dear Ms Christina Maree

RESEARCH PROPOSAL: A STUDY OF PRE-SERVICE SCIENCE TEACHERS' PEDAGOGICAL USE OF MULTIPLE REPRESENTATIONS DURING LESSON PRESENTATIONS

Your application to conduct the above-mentioned research in schools in the Western Cape has been approved subject to the following conditions:

1. Principals, educators and learners are under no obligation to assist you in your investigation.
2. Principals, educators, learners and schools should not be identifiable in any way from the results of the investigation.
3. You make all the arrangements concerning your investigation.
4. Educators' programmes are not to be interrupted.
5. The Study is to be conducted from **10 July 2019 till 27 September 2019**
6. No research can be conducted during the fourth term as schools are preparing and finalizing syllabi for examinations (October to December).
7. Should you wish to extend the period of your survey, please contact Dr A.T Wyngaard at the contact numbers above quoting the reference number?
8. A photocopy of this letter is submitted to the principal where the intended research is to be conducted.
9. Your research will be limited to the list of schools as forwarded to the Western Cape Education Department.
10. A brief summary of the content, findings and recommendations is provided to the Director: Research Services.
11. The Department receives a copy of the completed report/dissertation/thesis addressed to:
    The Director: Research Services
    Western Cape Education Department
    Private Bag X9114
    CAPE TOWN
    8000

We wish you success in your research.

Kind regards.
Signed: Dr Audrey T Wyngaard
Directorate: Research
DATE: 13 March 2019

ADDENDUM D: Letter of Ethical Clearance Research Ethics Committee: Humanities, Stellenbosch University

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NOTICE OF APPROVAL

REC: Social, Behavioural and Education Research (SBER) - Initial Application Form

6 November 2019

Project number: 9030

Project Title: A study of pre-service science teachers' pedagogical use of multiple representations during lesson presentations

Dear Miss Christina Maree

Co-investigators:

Mr. Nazeem Edwards

Your REC: Social, Behavioural and Education Research (SBER) - Initial Application Form submitted on 13 August 2019 was reviewed and approved by the REC: Humanities.

Please note the following for your approved submission:

Ethics approval period:

Protocol approval date (Humanities)	Protocol expiration date (Humanities)
6 November 2019	5 November 2022

GENERAL COMMENTS:

Please take note of the General Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

If the researcher deviates in any way from the proposal approved by the REC: Humanities, the researcher must notify the REC of these changes.

Please use your SU project number (9030) on any documents or correspondence with the REC concerning your project.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

FOR CONTINUATION OF PROJECTS AFTER REC APPROVAL PERIOD

Please note that a progress report should be submitted to the Research Ethics Committee: Humanities before the approval period has expired if a continuation of ethics approval is required. The Committee will then consider the continuation of the project for a further year (if necessary)

Included Documents:

Document Type	File Name	Date	Version
Informed Consent Form	consent letter	28/02/2019	1
Data collection tool	Interview guide	28/02/2019	1
Proof of permission	Research approval letter WCED	13/03/2019	1
Proof of permission	Research approval letter WCED	13/03/2019	1
Proof of permission	Institutional Permission_Standard Agreement A study of pre-service science teachers' pedagogical use of multiple representations during lesson presentations	28/03/2019	1
Proof of permission	Institutional Permission_Standard Agreement A study of pre-service science teachers' pedagogical use of multiple representations during lesson presentations	29/03/2019	1

Informed Consent Form	consent letter	29/05/2019	updated
Informed Consent Form	Parental Consent Form	29/05/2019	1
Research Protocol/Proposal	Final proposal CE Maree 16987373	26/07/2019	1
Data collection tool	Description of the multimedia files, images or the text that will be recorded or analysed for this project	27/07/2019	1
Informed Consent Form	consent letter	27/07/2019	3
Data collection tool	Interview guide	27/07/2019	2
Data collection tool	Description of the multimedia files, images or the text that will be recorded or analysed for this project	27/07/2019	2
Data collection tool	Observation and coding guide	27/07/2019	1

If you have any questions or need further help, please contact the REC office at cgraham@sun.ac.za.

Sincerely,

Clarissa Graham

REC Coordinator: Research Ethics Committee: Human Research (Humanities)

National Health Research Ethics Committee (NHREC) registration number: REC-050411-032.
The Research Ethics Committee: Humanities complies with the SA National Health Act No.61 2003 as it pertains to health research. In addition, this committee abides by the ethical norms and principles for research established by the Declaration of Helsinki (2013) and the Department of Health Guidelines for Ethical Research: Principles Structures and Processes (2nd Ed.) 2015. Annually a number of projects may be selected randomly for an external audit.

Investigator Responsibilities

Protection of Human Research Participants

Some of the general responsibilities investigators have when conducting research involving human participants are listed below:

1.Conducting the Research. You are responsible for making sure that the research is conducted according to the REC approved research protocol. You are also responsible for the actions of all your co-investigators and research staff involved with this research. You must also ensure that the research is conducted within the standards of your field of research.

2.Participant Enrollment. You may not recruit or enroll participants prior to the REC approval date or after the expiration date of REC approval. All recruitment materials for any form of media must be approved by the REC prior to their use.

3.Informed Consent. You are responsible for obtaining and documenting effective informed consent using **only** the REC-approved consent documents/process, and for ensuring that no human participants are involved in research prior to obtaining their informed consent. Please give all participants copies of the signed informed consent documents. Keep the originals in your secured research files for at least five (5) years.

4.Continuing Review. The REC must review and approve all REC-approved research proposals at intervals appropriate to the degree of risk but not less than once per year. There is **no grace period.** Prior to the date on which the REC approval of the research expires, **it is your responsibility to submit the progress report in a timely fashion to ensure a lapse in REC approval does not occur.** If REC approval of your research lapses, you must stop new participant enrollment, and contact the REC office immediately.

5.Amendments and Changes. If you wish to amend or change any aspect of your research (such as research design, interventions or procedures, participant population, informed consent document, instruments, surveys or recruiting material), you must submit the amendment to the REC for review using the current Amendment Form. You **may not initiate** any amendments or changes to your research without first obtaining written REC review and approval. The **only exception** is when it is necessary to eliminate apparent immediate hazards to participants and the REC should be immediately informed of this necessity.

6.Adverse or Unanticipated Events. Any serious adverse events, participant complaints, and all unanticipated problems that involve risks to participants or others, as well as any research related injuries, occurring at this institution or at other performance sites must be reported to Malene Fouche within **five (5) days** of discovery of the incident. You must also report any instances of serious or continuing problems, or non-compliance with the RECs requirements for protecting human research participants. The only exception to this policy is that the death of a research participant must be reported in accordance with the Stellenbosch University Research Ethics Committee Standard Operating Procedures. All reportable events should be submitted to the REC using the Serious Adverse Event Report Form.

7.Research Record Keeping. You must keep the following research related records, at a minimum, in a secure location for a minimum of five years: the REC approved research proposal and all amendments; all informed consent documents; recruiting materials; continuing review reports; adverse or unanticipated events; and all correspondence from the REC

8.Provision of Counselling or emergency support. When a dedicated counsellor or psychologist provides support to a participant without prior REC review and approval, to the extent permitted by law, such activities will not be recognised as research nor the data used in support of research. Such cases should be indicated in the progress report or final report.

9.Final reports. When you have completed (no further participant enrollment, interactions or interventions) or stopped work on your research, you must submit a Final Report to the REC.

10.On-Site Evaluations, Inspections, or Audits. If you are notified that your research will be reviewed or audited by the sponsor or any other external agency or any internal group, you must inform the REC immediately of the impending audit/evaluation.

ADDENDUM E: Letter of Consent for Participants

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STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

Title of study: A study of pre-service science teachers' pedagogical use of multiple representations during lesson presentations

You are asked to participate in a research study conducted by Lize Maree (BSc, PGCE, BEd HONS (Science Education) (SU), from the Curriculum Studies Department at Stellenbosch University. The results of the study will contribute to a master's thesis research (MEd). You were selected as a possible participant in this study because you are currently enrolled as a prospective science teacher at Stellenbosch University. As a prospective science teacher at Stellenbosch University you are either enrolled as a 4^{th} year B.Ed student taking Natural Sciences as a module or a PGCE student taking Physical Sciences as a module.

1. PURPOSE OF THE STUDY

This study is focused on the way in which pre-service science teachers use multiple representations during lessons in the classroom. There will be a distinction between Physics and Chemistry during the presented lessons.

2. PROCEDURES

If you volunteer to participate in this study, I would ask you to do the following things:

- Allow me to video record your lesson presented during micro-teaching sessions and practical teaching at schools.
- Allow me to access lesson plans.
- Be available for a follow up interview after lessons was video recorded (not necessarily directly after).
- Be willing to make content or teaching aids used during sessions available to me afterwards.

3. POTENTIAL RISKS AND DISCOMFORTS

There are no risks attached to the study other than the usual participation of a student during classroom activities and lesson presentations.
No extra time is required except time needed for interviews.

4. PAYMENT FOR PARTICIPATION

The participants do not receive any payment for participation in the study.

5. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

Confidentiality will be maintained by **utilizing codes instead of the participants' names. The data collected in the form of hard copies of interviews, will be stored under lock and key in my supervisor Dr Nazeem Edwards's office at Stellenbosch University. Numeric data and electronic copies of information will be kept on the researcher's computer and access will be granted to personnel involved in the study, namely the supervisor and authorized Stellenbosch University staff.**

Any video-recordings are subject to you reviewing the information. These will be used for the purposes of the study which is educational by nature, and any publication that may emanate will maintain strict confidentiality.

6. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. If you want to withdraw, you should do so in writing and send it to lizemaree@sun.ac.za. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. Whether you choose to participate or decline participation there will be no negative consequences. Your success in your enrolled module is not determined by your participation or non-participation in this study.

7. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact Lize Maree (lizemaree@sun.ac.za) or Dr Nazeem Edwards (supervisor) (nedwards@sun.ac.za).

8. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

The information above was described to me by Lize Maree in English and I am in command of this language. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent voluntarily to participate in this study/I hereby consent that the subject/participant may participate in this study. I have been given a copy of this form.

____
Name of Subject/Participant

____________________________ ____________________
Signature of Subject Date

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to

____
Name of Subject/Participant

[He/she] was encouraged and given ample time to ask me any questions. This conversation was conducted in [Afrikaans/*English] and no translator was used.

Signature of Investigator Date

ADDENDUM F: Parental Consent Information

Parental Consent Information

Dear Parents/Guardians

I, Lize Maree (BSc, PGCE, BEd HONS (Science Education) (Stellenbosch University), wish to undertake a study at selected High Schools in the Western Cape that will require the observation and video recording of the pre-service Science teachers doing their practical teaching at the school where your child is currently enrolled. These pre-service teachers are final year education students from Stellenbosch University placed at the respective schools by Stellenbosch University, the same institution where I am currently enrolled for my Master's studies. The observation and video recording of the pre-service Science teachers is part of my data collection process for abovementioned qualification. This will take place during the third school term of 2019.

The title of my study is "A study of pre-service science teachers' pedagogical use of multiple representations during lesson presentations". The focus of this study is to look at how pre-service science teachers make use of different modes of representation to explain and communicate scientific concepts. It is important to note that this study focus on the pre-service teacher and not the learners being taught.

During this process I will be observing and video recording one science lesson the pre-service teacher presents in the classroom at the school where your child is. At no point during this process will your child be observed or video recorded for the purpose of this study. The observation and recording may be conducted by me or by my study supervisor, Dr Nazeem Edwards.

The purpose of this letter is to inform you about my presence in the classroom, what I plan to do in the classroom and to assure you that your child will not be part of the focus of the observations or video recordings.

The study is ethically approved by Stellenbosch University and the Western Cape Education Department (WCED).

Should you have questions or need clarification on the matter, please feel free to contact:

Lize Maree (researcher)

email: lizemaree@sun.ac.za

Dr Nazeem Edwards (research supervisor)

email: nedwards@sun.ac.za

Your support is greatly appreciated.

ADDENDUM G: Group A Assignment

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DEPARTEMENT KURRIKULUMSTUDIE
NATUURWETENSKAPPE 277
Elektrisiteitsprojek/*Electricity Project*

Werk met 'n klasmaat om 'n projek te skep om van die beginsels in elektrisiteit wat jy geleer het toe te pas. Apparaat (kit) sal verskaf word.

Demonstreer hoe dit werk en verduidelik hoe dit werk. Maak 'n video-opname waarin jy 'n simulasie gebruik

Work with a classmate to design a project to apply some of the principles in electricity that you have learnt. Apparatus (kit) will be supplied.

Demonstrate how it works and explain how it works. Make a video recording in which you use a simulation.

Due date: 10 JUNE 2019

Upload on Sunlearn with your names_studentnos as filename.

1. ***Rubric for assessment of project model***

Assessment Criteria	Performance level indicators			
				Mark
	7-10	**3-6**	**0-2**	
Creativity	Materials are creatively portrayed in ways that enhance understanding about the subject matter. Great care was taken in the construction process so that the model is neat and attractive. The student demonstrates a total understanding.	There was an attempt to use materials in a creative way. Construction was careful and accurate for the most part, but 1-2 details could have been refined for a more attractive product. The student demonstrates a proficient understanding.	Construction demonstrated some effort, but 3-4 details could have been refined for a more attractive product. The student demonstrates a basic understanding.	
	7-10	**3-6**	**0-2**	
Accuracy	Project model displays a high level of accuracy in the manner components are connected	Project model displays a moderate level of accuracy in the manner components are connected.	Project model displays an inadequate level of accuracy in the manner components are connected.	
	4-5	**2-3**	**0-1**	
Function	All components function	1 or 2 of the components do not function	3 or more of the components do not function	
	12-15	**6-11**	**0-5**	
Explanation	All scientific principles are comprehensively explained and the student demonstrates excellent understanding	Scientific principles are explained with a degree of inaccuracy and the student demonstrates moderate understanding	Scientific principles are explained with many inaccuracies and the student demonstrates inadequate understanding	
			Total	**/40**

2. **VIDEO presentation rubric/*aanbiedingsrubriek***

20 — **Rating Scale/*Graderingskaal* →** ↓ **Assessment criteria** ***Assesseringskriteria*** **Weighted/*Gewig***	**Excellent** ***Uitstekend***	**Good** ***Goed***	**Satisfactory** ***Bevredigend***	**Needs some more work** ***Benodig nog meer werk***	**Needs much more work** ***Benodig nog baie meer werk***	**Not addressed** ***Nie aangespreek nie***
CONTENT/*INHOUD* (10)	**9-10**	**7-8**	**5-6**	**3-4**	**1-2**	**0**
Content is relevant and insightful. *Inhoud is relevant en insiggewend.*						
ORIGINALITY/*OORSPRONKLIKHEID* (5)	**5**	**4**	**3**	**2**	**1**	**0**
Material shows a high degree of originality. *Materiaal het 'n hoë gehalte van oorspronklikheid.*						
PRESENTATION FEATURES/ *AANBIEDINGSKENMERKE* (5)	**5**	**4**	**3**	**2**	**1**	**0**
Overall presentation – well organised. *Algehele aanbieding – goed georganiseer.*						
Comment/*Kommentaar*:						

ADDENDUM H: Group B Assignment

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Natural Sciences 478

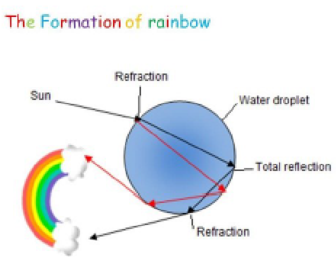
Lesson plan & video assignment

You may work with a partner and submit one assignment.

Refer to chapter 4 - Visible light in the textbook on Sunlearn Science-Grade-8B-English-Learners. It gives you an idea where the content fits in with the CAPS and what you should be familiar with when teaching Senior Phase Natural Sciences.

1. Draw up a lesson plan on any of the topics in the chapter.
   - Include appropriate content and indicate your teaching approach.
   - Indicate all the materials and resources that you will use.
2. Draw up an assessment activity using Socrative.
   - The questions must cover different cognitive levels.
3. Make a video recording of the lesson in which you explain the key concepts.
   - You must focus on the micro-level when explaining a phenomenon, e.g. how does a rainbow form?

The refraction of light at two boundaries of the droplet results in the dispersion of light into a spectrum of colours. The shorter wavelength blue and violet light refract a slightly greater amount than the longer wavelength red light. Since the boundaries are not parallel to each other, the double refraction results in a distinct separation of the sunlight into its component colours.



SEE RUBRICS BELOW.

Assessment Criteria	Performance level indicators			
				Mark
	7-10	3-6	0-2	
Planning	Outcomes very clearly articulated with appropriate plan/structure to achieve them.	Outcomes clearly articulated with partially appropriate plan/structure to achieve them.	Outcomes unclear with inappropriate plan/structure to achieve them.	
	7-10	3-6	0-2	
Content & pedagogy	All key concepts are included with appropriate pedagogical approaches.	Some key concepts are included with some appropriate pedagogical approaches.	No key concepts are included with inappropriate pedagogical approaches.	
	4-5	2-3	0-1	
Learner engagement	Clear scaffolding to build on learner's prior knowledge.	Some scaffolding to build on learner's prior knowledge.	No scaffolding to build on learner's prior knowledge.	
	4-5	2-3	0-1	
Materials & resources	All materials and resources are appropriate to the grade level.	Some materials and resources are appropriate to the grade level.	No materials and resources are appropriate to the grade level.	
	7-10	3-6	0-2	
Assessment (SOCRATIVE – attach evidence)	Clearly linked to outcomes & includes higher-order questions.	Vaguely linked to outcomes & only includes middle-order questions.	Not linked to outcomes & only includes lower-order questions.	
			Total	/40

20 — **Rating Scale**/***Graderingskaal*** → ↓ **Assessment criteria** ***Assesseringskriteria*** **Weighted**/***Gewig***	Excellent ***Uitstekend***	Good ***Goed***	Satisfactory ***Bevredigend***	Needs some more work ***Benodig nog meer werk***	Needs much more work ***Benodig nog baie meer werk***	Not addressed ***Nie aangespreek nie***
CONTENT / *INHOUD* (10)	9-10	7-8	5-6	3-4	1-2	0
Content is relevant and insightful. *Inhoud is relevant en insiggewend.*						
EXPLANATION /VERDUIDELIKING (10)	9-10	7-8	5-6	3-4	1-2	0
Explanation focuses on microlevel. *Verduideliking focus op mikrovlak.*						
Comment/*Kommentaar*:						

ADDENDUM I: Group C Assignment

MATTER & MATERIALS: Part 1 (work in pairs)

1. Choose a section from Senior Phase Natural Sciences and plan a lesson for a Grade 7/8 class. Make use of the books on Sunlearn.
2. Complete the lesson planning form.
3. Include 10 short assessment questions that were done in Socrative.
4. Submit during classtime **23 October**.

Assessment Criteria	Performance level indicators			
				Mark
	7-10	3-6	0-2	
Planning	Outcomes very clearly articulated with appropriate plan/structure to achieve them.	Outcomes clearly articulated with partially appropriate plan/structure to achieve them.	Outcomes unclear with inappropriate plan/structure to achieve them.	
	7-10	3-6	0-2	
Content & pedagogy	All key concepts are included with appropriate pedagogical approaches.	Some key concepts are included with some appropriate pedagogical approaches.	No key concepts are included with inappropriate pedagogical approaches.	
	4-5	2-3	0-1	
Learner engagement	Clear scaffolding to build on learner's prior knowledge.	Some scaffolding to build on learner's prior knowledge.	No scaffolding to build on learner's prior knowledge.	
	4-5	2-3	0-1	
Materials & resources	All materials and resources are appropriate to the grade level.	Some materials and resources are appropriate to the grade level.	No materials and resources are appropriate to the grade level.	
	7-10	3-6	0-2	
Assessment (SOCRATIVE – attach evidence)	Clearly linked to outcomes & includes higher-order questions.	Vaguely linked to outcomes & only includes middle-order questions.	Not linked to outcomes & only includes lower-order questions.	
			Total	/40

Part 2 (work in pairs)

1. You must do a practical demonstration of any of the concepts out of the lesson and make a video recording.
2. Explain what is observed.
3. Submit **11 November 2019** at lab.

20 **Rating Scale/*Graderingskaal*** → ↓ **Assessment criteria** ***Assesseringskriteria*** **Weighted/*Gewig***	Excellent *Uitstekend*	Good *Goed*	Satisfactory *Bevredigend*	Needs some more work *Benodig nog meer werk*	Needs much more work *Benodig nog baie meer werk*	Not addressed *Nie aangespreek nie*
CONTENT / *INHOUD* (10)	**9-10**	**7-8**	**5-6**	**3-4**	**1-2**	**0**
Content is relevant and insightful. *Inhoud is relevant en insiggewend.*						
EXPLANATION /VERDUIDELIKING (10)	**9-10**	**7-8**	**5-6**	**3-4**	**1-2**	**0**
Explanation focuses on microlevel. *Verduideliking fokus op mikrovlak.*						
Comment/*Kommentaar*:						

ADDENDUM J: Group D Assignment

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Natural Sciences 378

ASSESSERINGSTAAK / ASSESSMENT TASK

MATTER & MATERIALS / MATERIE & MATERIALE

SPERDATUM/ DEADLINE: 14 JUNE 2019

INSTRUKSIES: Verwys na die handboek Wetenskap-Gr-9A-Afrikaans-Leerders op Sunlearn – Hoofstukke 2, 3 & 4. Julle kan in pare werk.

INSTRUCTIONS: Refer to the textbook Science-Grade-9A-English-Learners on Sunlearn – Chapters 2, 3 & 4. You may work in pairs.

In hoofstuk 2 word sekere kernkonsepte verduidelik. Kies 'n toepassing uit hoofstuk 3 of 4 om hierdie kernkonsepte aan te spreek.

Jy moet a maksimum van 10 powerpoint skyfies voorberei met 'n verduideliking van elk ingesluit (audio). Laai dit op SUNLEARN op.

In chapter 2 certain key concepts are explained. Choose an application in chapter 3 or 4 to address these key concepts.

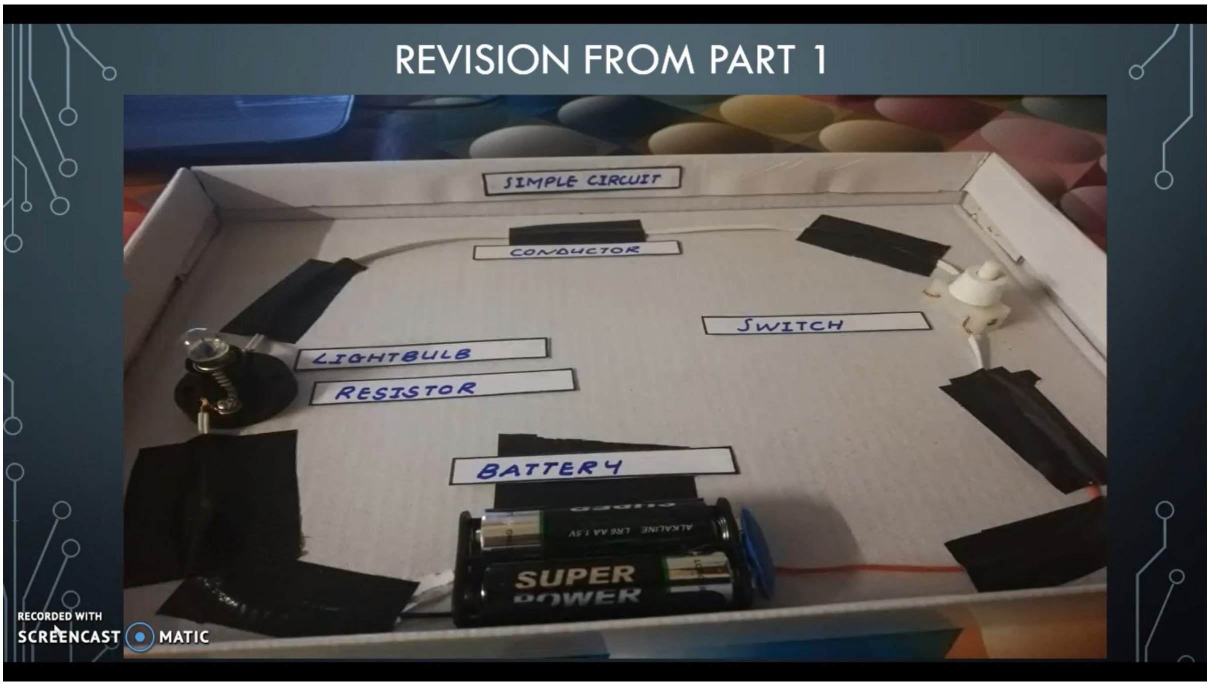
You must prepare a maximum of 10 slides with an explanation of each included (audio). Upload it on SUNLEARN.

MATTER & MATERIALS: POWERPOINT OPDRAG

Assessment Criteria	Performance level indicators			
				Mark
	4-5	2-3	0-1	
Planning	Outcomes very clearly articulated with appropriate plan/structure to achieve them.	Outcomes clearly articulated with partially appropriate plan/structure to achieve them.	Outcomes unclear with inappropriate plan/structure to achieve them.	
	7-10	3-6	0-2	
Content	All key concepts are included with appropriate explanations.	Some key concepts are included with some appropriate explanations.	No key concepts are included with inappropriate explanations.	
	4-5	2-3	0-1	
Materials & resources	All materials and resources are appropriate for the grade level.	Some materials and resources are appropriate for the grade level.	No materials and resources are appropriate for the grade level.	
			Total	**/20**

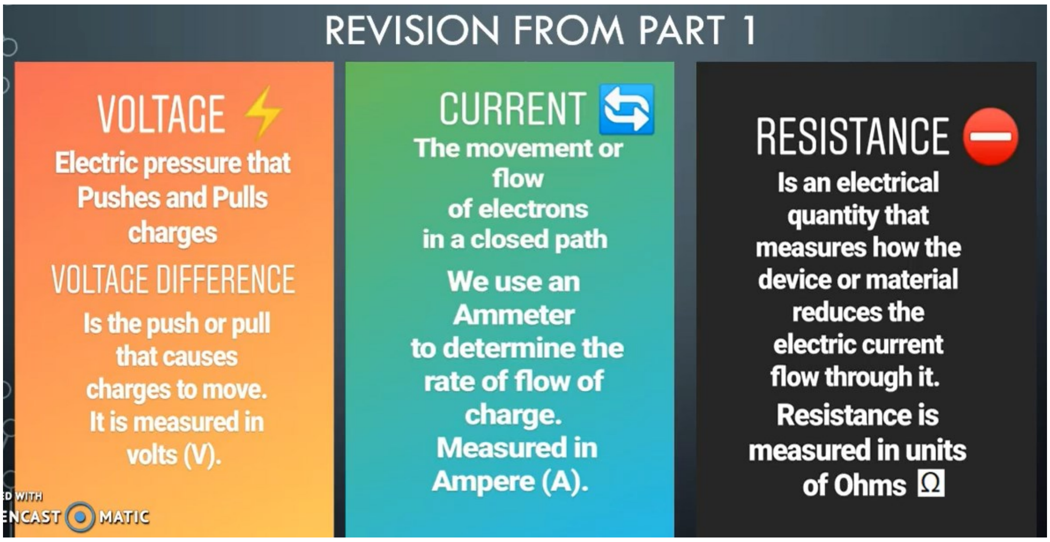
ADDENDUM K: Example of Lesson Coding

The lesson analysed below is an example of how all video recorded lessons were analysed for the purpose of this study. This is also an example of a lesson presentation that scored an overall high competence and fluency coding. Where a note is made with an asterisk (*) the researcher is pointing out an observation or relevant side note. Where writing is written in red, an issue is emphasised. The coding is indicated in blue, aligned to the right hand side of the page. The codes were fed into an Excel spreadsheet together with all the other lessons' codes as indicated below the coding of this lesson.



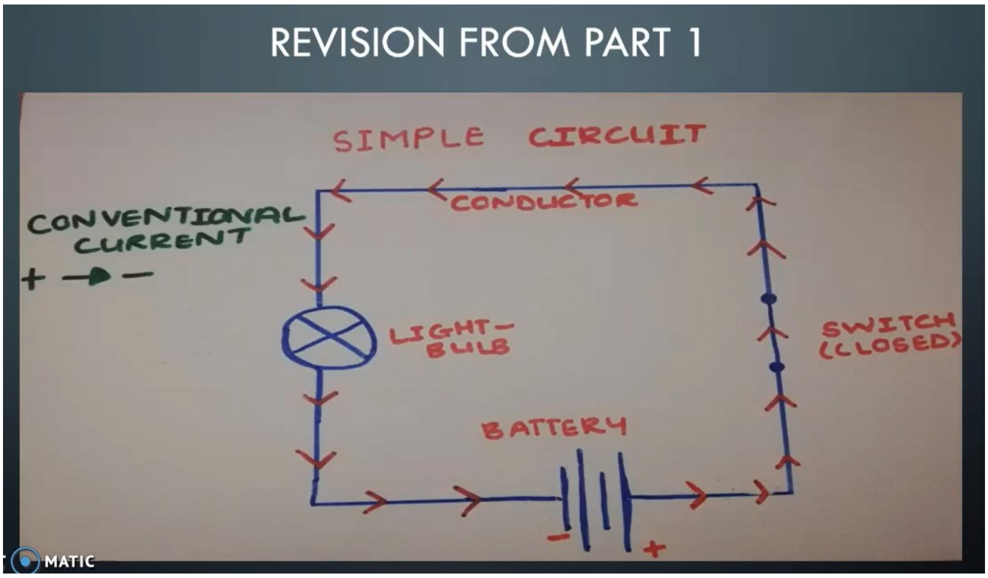
EXPERIMENTAL 3

We looked at a simple circuit, which contains a minimum of 3 components. Our circuit includes a switch, battery, lightbulb that acted as a resistor, conductor.



EXPERT WORDS 3

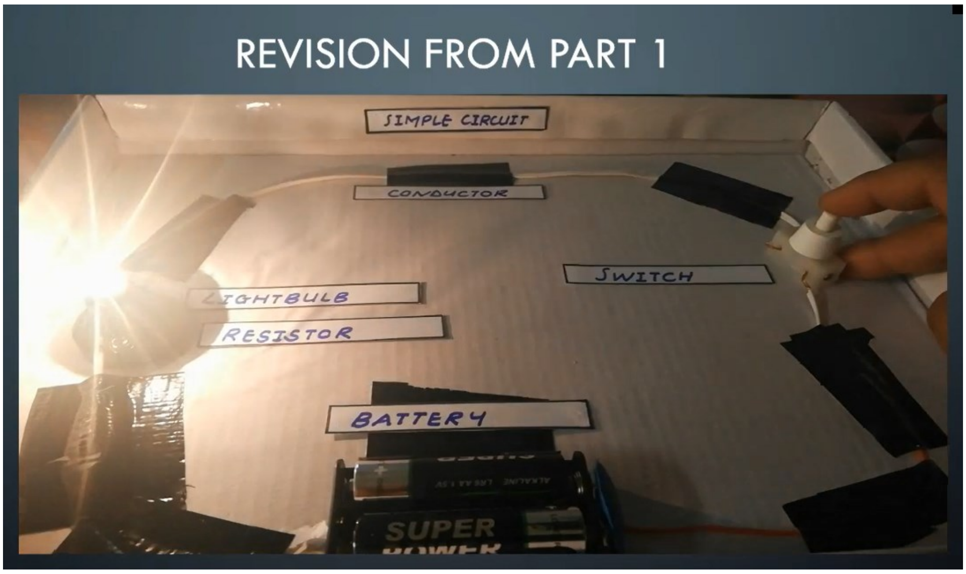
*Reads from the screen word for word



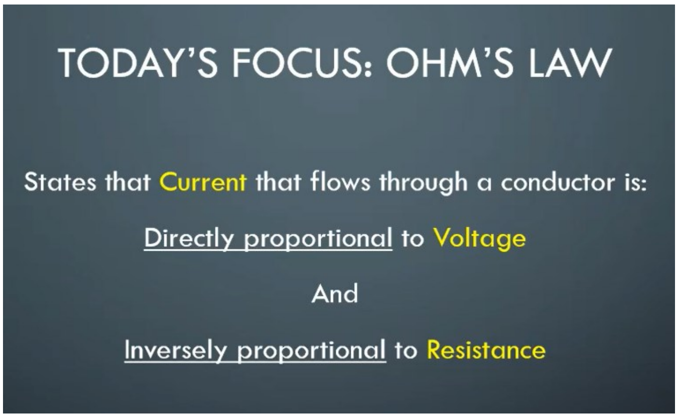
GRAPHICAL 3

A drawing of a simple circuit, with conventional current, explaining that positive (+) charges flow from the positive (+) terminal through the circuit into the negative (–) terminal.

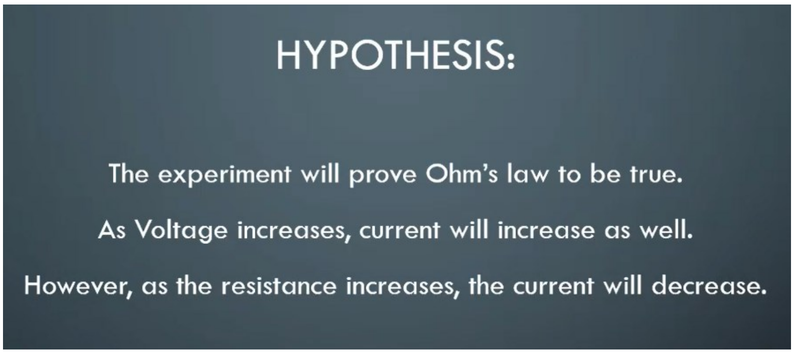
EXPERT WORDS 2



We took a look at the circuits function where we used two 1.5V batteries, we put it in our circuit and looked at the outcome. *closes the switch on the circuit and the lightbulb shines.



*Reads from the screen word for word

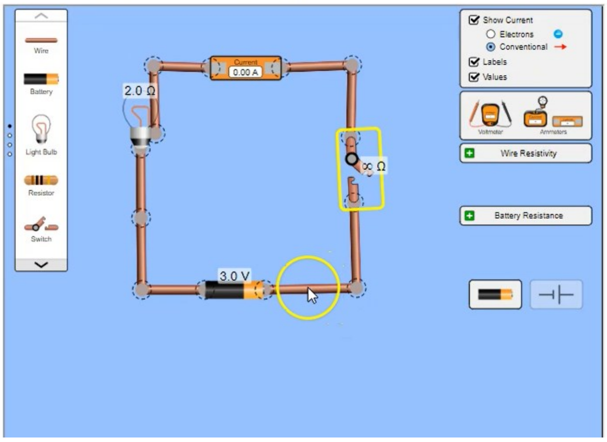


The hypothesis for today is that the experiment will prove Ohm's law to be true. This means... *Reads from the screen word for word.

EXPERT WORDS 2

*(what is hypothesis????) ; (if _____ remains constant????)

circuit-construction-kit-dc en (1)



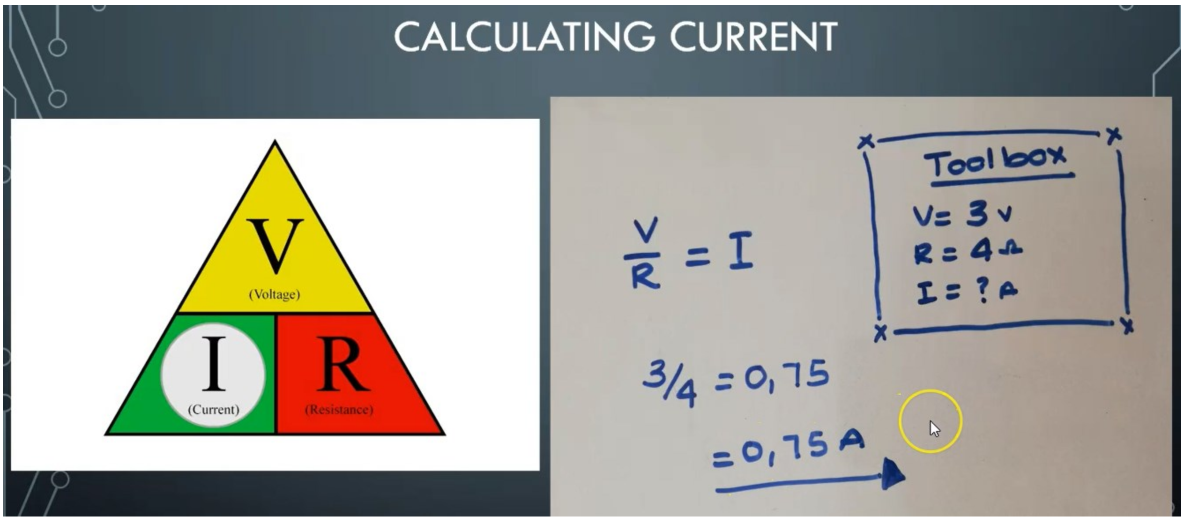
GRAPHICAL 3

As you can see the simulator is exactly the same except that it includes the ammameter. However we can exclude the ammameter, and calculate it using the formula V over R.

EXPERT WORDS 2

*pronounces ammeter as ammameter

*what is *it*?



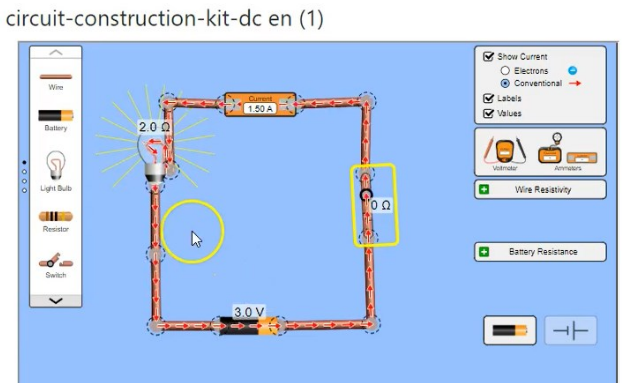
The formula V over R, voltage over resistance will give us current.

*mentions that 3 over 4 means 3 divided by 4

This means we have zero point seventy five amps. We will use this to calculate the current when we do not have the ammeter *(does not mention that we will then need the resistance and voltage)

EXPERT WORDS 2

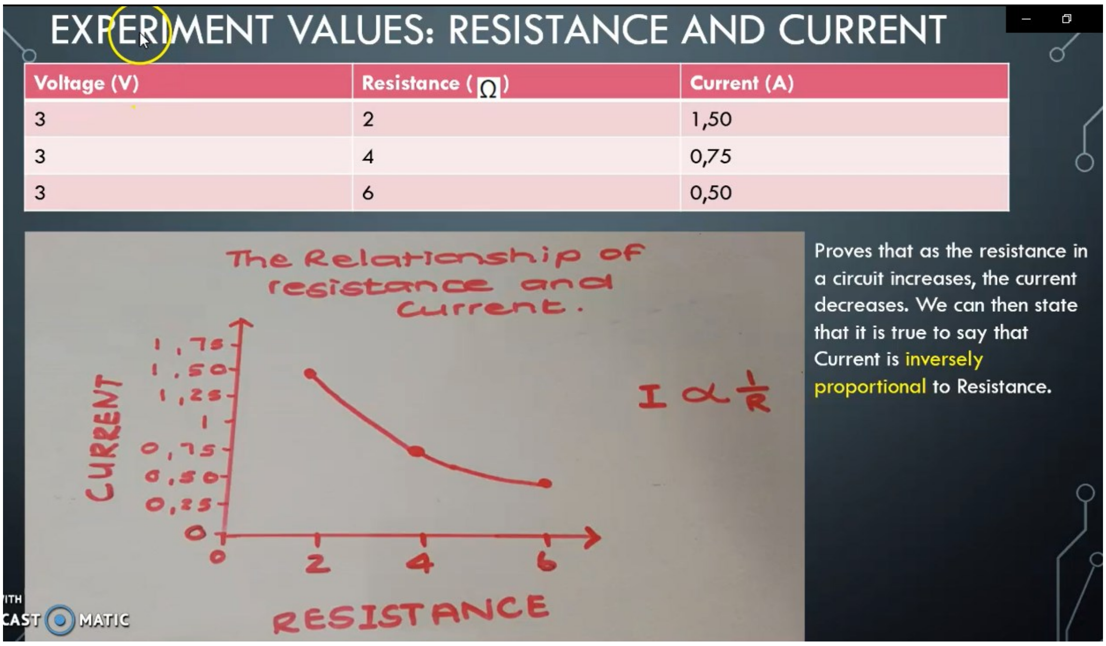
SYMBOLIC 3



I have set the simulator to use conventional current, and can see the labels and values. The switch is now on. *on and off versus closed and open

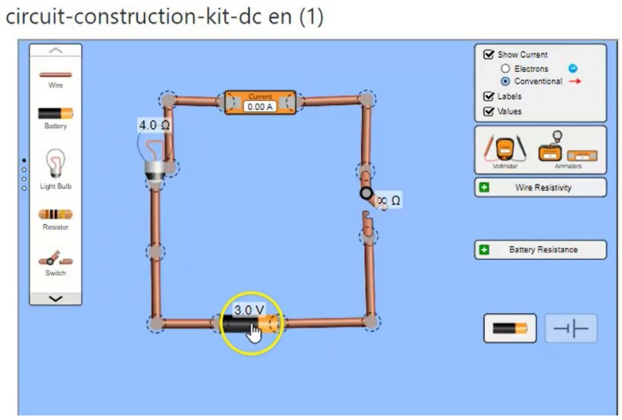
As you can see 2 ohms gives us a current of one point 50. *no unit

If we change the units of the ohms to 4, let see what happens – current slows down, 0.75A and the bulb is less brighter than before. If we change to a resistance of 6 ohms, we now have a current of zero point 50 amps, as you can see the bulb is now very dim, and the charges is very slow.

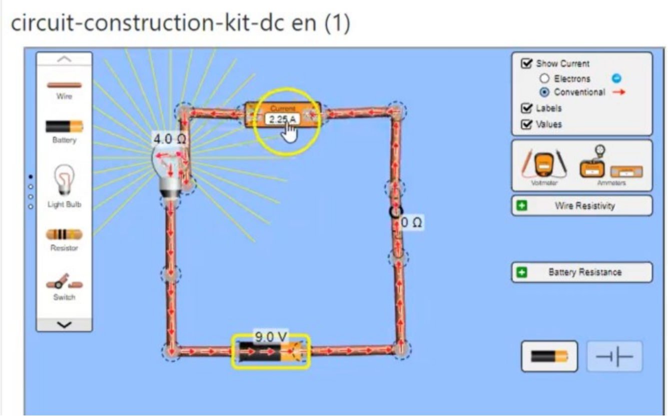


GRAPHICAL 3

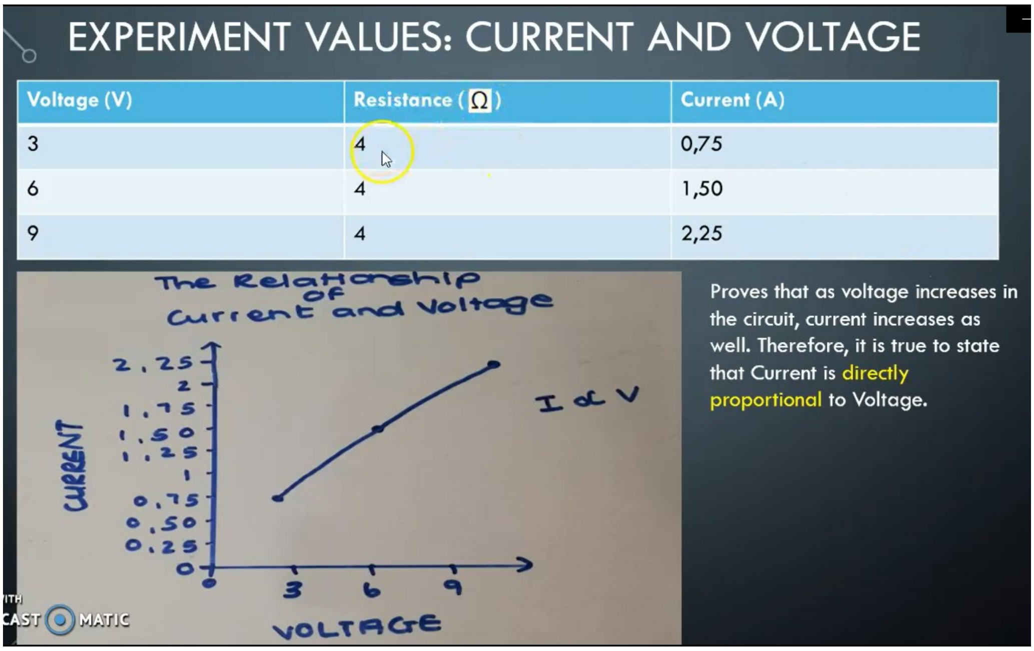
I have placed experiment values of resistance and current into a table to illustrate what we are trying to prove. The voltage remains 3 Volts throughout the experiment, resistance and current change. The graph illustrates the relationship between resistance and current. As you can see as resistance increased, current decreased. Therefore we can state that it is true to say that current is inversely proportional to resistance. *if V is kept constant



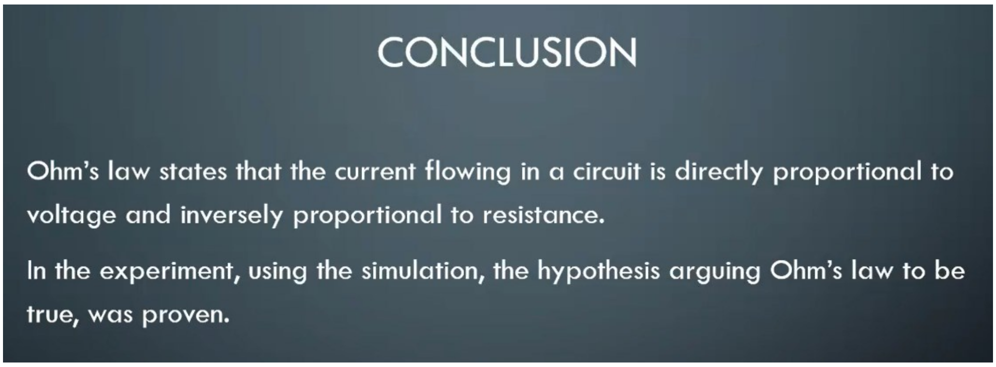
In this simulation, fixed resistance of 4 ohm, and this time the battery, sorry, the voltage will change. So lets switch it on... as you can see 3 volts and 4 ohms the current reading is 0.75 amp. If we change the voltage to 6 volts, the current is moving way faster and is now at 1.50 amps look how bright that bulb is.



Change once again to 9 volts, we can see that bulb is way brighter and the current is moving at 2.25 amps.



Placed experimental values in the table. Resistance remained 4 ohm. The graph illustrates the relationship between current and voltage. As you can see as voltage increased so did current. Therefore it is true to state that current is directly proportional to voltage. *if R is kept constant



NS WORDS 3

*Reads from the screen word for word

CODES

Project	Topic (type in)		coding 0-3				
	Physics	Chemistry	Graphical	Experimental	Symbolic	Non-specialist Words	Expert Words
1	series circuits		2	2	0	2	1
2	series circuits		3	2	0	3	1
3	parallel circuits		3	2	0	3	1
4	s/p circuit		2	0	0	1	1
5	series circuits		3	2	0	3	2
6	series circuits		3	3	0	2	1
7	series circuits		1	3	0	2	2
8	s/p circuit		2	2	0	2	1
9	parallel circuits		2	1	0	1	1
10	parallel circuits		3	2	0	3	1
11	s/p circuit		3	2	1	2	1
12	series circuits		3	1	0	3	1
13	general circuit		3	3	3	3	2
14	series circuits		3	2	0	3	1
15	series circuits		1	0	0	0	0
16	general circuit		1	2	0	1	1
17	parallel circuits		1	1	1	3	1
18	series circuits		3	0	0	2	1
19	parallel circuits		0	2	0	2	1
20	parallel circuits		1	1	0	1	1
21	series circuits		1	1	0	1	0
22	series circuits		2	1	0	2	1
23	parallel circuits		1	2	0	1	0
24	series circuits		3	1	2	3	2
25	parallel circuits		3	1	0	3	3
26	series circuits		2	2	0	2	1
27	series circuits		3	2	3	3	2
28	series circuits		0	2	1	2	1
29	series circuits		3	1	2	3	1
30	s/p circuit		3	1	0	2	1
31	parallel circuits		0	1	0	0	0
32	series circuits		2	2	0	3	1
33	s/p circuit		3	1	1	3	1
34	series circuits		1	2	0	1	1
35	s/p circuit		0	3	0	2	1
36	series circuits		1	2	0	1	0
37	series circuits		2	2	0	2	0
38	series circuits		0	1	0	1	0
39	parallel circuits		2	1	1	2	1
40	parallel circuits		2	2	0	3	1

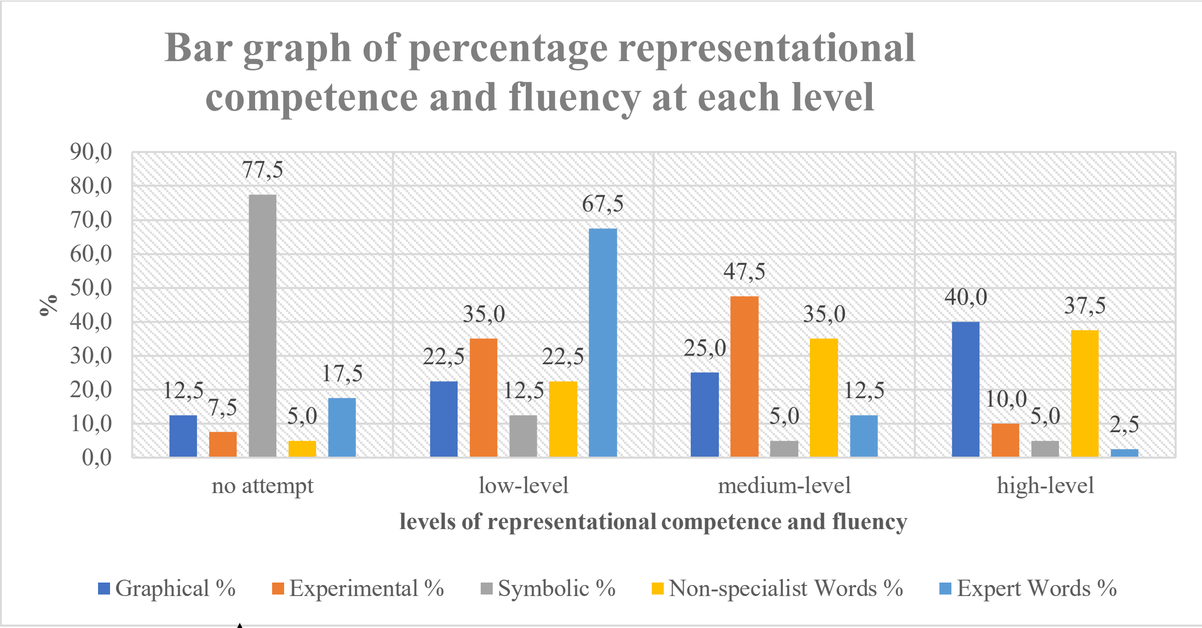
CODES ADDED TO THE EXCEL SPREADSHEET. THE EXAMPLE ABOVE WAS FOR LESSON 13 GROUP A.

Level	Graphical	Experimental	Symbolic	Non-specialist Words	Expert Words
no attempt	5	3	31	2	7
low-level	9	14	5	9	27
medium-level	10	19	2	14	5
high-level	16	4	2	15	1
total	40	40	40	40	40

Level	Graphical %	Experimental %	Symbolic %	Non-specialist Words %	Expert Words %
no attempt	12,5	7,5	77,5	5,0	17,5
low-level	22,5	35,0	12,5	22,5	67,5
medium-level	25,0	47,5	5,0	35,0	12,5
high-level	40,0	10,0	5,0	37,5	2,5

CODES WERE TALLIED IN THE EXCEL SPREADSHEET FOR EACH LEVEL OF EACH REPRESENTATIONAL MODE

CODES WERE EXPRESSED AS A PERCENTAGE OF THE GROUP IN THE EXCEL SPREADSHEET FOR EACH LEVEL OF EACH



PERCENTAGES WAS REPRESENTED AS A BAR GRAPH TO GIVE A VISUAL REPRESENTATION OF CODING RESULTS

ADDENDUM L: Expert Words Identified

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
		• Revise the classification of metalloids by their characteristic property of increasing conductivity with increasing temperature (the reverse of metals) e.g. silicon and graphite. • Identify the metalloids and their position on the periodic table			
0.25 hours	Electrical conductors, semiconductors and insulators	• Revise the classification of materials as: electrical conductors, semiconductors and insulators • Give examples of electrical conductors, semiconductors and insulators • Identify the substances and the 'appliances or objects', that are in common daily use in homes and offices, that are specifically chosen because of their electrical properties (conductors, insulators and semi-conductors)	• Test the following substance to classify them as conductors, semiconductors or insulators: glass, wood, graphite, copper, zinc, aluminium and materials of your own choice		
0.25 hours	Thermal conductors and insulators	• Revise how to test and classify materials as thermal conductors and insulators • Give examples of materials that are thermal conductors and insulators	• Test the following substance to classify them as heat conductors, or insulators: glass, wood, graphite, copper, zinc, aluminium and materials of your own choice		

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
0.5 hour	Force exerted by charges on each other (descriptive) Attraction between charged and uncharged objects (polarisation)	• Recall that like charges repel and opposite charges attract • Explain how charged objects can attract uncharged insulators because of the polarization of molecules inside insulators	**Practical Demonstration:** 1. Rub a balloon against dry hair to charge it. Bring the charged balloon, rubbed against dry hair, near a stream of smooth flowing water (laminar flow) 2. Demonstrate everyday examples of the effect of electrostatics	**Materials:** Balloon, plastic pen, small pieces of paper, stream of smooth flowing water	In materials that comprise polarised molecules, these molecules may rotate when brought near to a charged object, so that one side of the object is more positive and the other side more negative, even though the object as a whole remains neutral.
8 HOURS	**Electric circuits**				
1 hour	emf, Terminal Potential Difference (terminal pd)	• Define potential difference in terms of work done and charge. V = W/Q • Know that the voltage measured across the terminals of a battery when no current is flowing through the battery is called the emf • Know that the voltage measured across the terminals of a battery when current is flowing through the battery is called terminal potential difference (terminal pd). • Know that emf and pd are measured in volts (V) • Do calculations using V = W/Q	**Practical Demonstrations:** Demonstrate how to measure emf and terminal potential difference: Set up a circuit to measure the emf and terminal potential difference and get learners to try to account for the discrepancy	**Materials:** Light bulbs, resistors, batteries, switches, connecting leads, ammeters, voltmeters	If possible, give learners the opportunity to connect meters in circuits. If the meters have more than one scale, always connect to the largest scale first so that the meter will not be damaged by having to measure values that exceed its limits. Note that voltage and potential difference are synonmous

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
1 hour	Current	• Define current, I, as the rate of flow of charge. It is measured in ampere (A), which is the same as coulomb per second • Calculate the current flowing using the equation $I = \frac{Q}{\Delta t}$ • Indicate the direction of the current in circuit diagrams (conventional)			The direction of current in a circuit is from the positive end of the battery, through the circuit and back to the negative end of the battery. In the past, this was called conventional current to distinguish it from electron flow. However, it is sufficient to call it the direction of the current and just mention that this is by convention. A very common misconception many learners have is that a battery produces the same amount of current no matter what is connected to it. While the emf produced by a battery is constant, the amount of current supplied depends on what is in the circuit.
1 hour	Measurement of voltage (pd) and current	• Draw a diagram to show how to correctly connect an ammeter to measure the current through a given circuit element • Draw a diagram to show how to correctly connect a voltmeter to measure the voltage across a given circuit element	**Practical Demonstrations:** Set up a circuit to measure the current flowing through a resistor or light bulb and also to measure the potential difference across a light bulb or resistor	**Materials:** Light bulbs, resistors, batteries, switches, connecting leads, ammeters, voltmeters	Make sure that learners know that the positive side of the meter needs to be connected closest to the positive side of the battery. An ammeter must be connected in series with the circuit element of interest; a voltmeter must be connected in parallel with the circuit element of interest.

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
1 hour	Resistance	• Define resistance • Explain that resistance is the opposition to the flow of electric current • Define the unit of resistance; one ohm (Ω) is one volt per ampere. • Give a microscopic description of resistance in terms of electrons moving through a conductor colliding with the particles of which the conductor (metal) is made and transferring kinetic energy. • State and explain factors that affect the resistance of a substance • Explain why a battery in a circuit goes flat eventually by referring to the energy transformations that take place in the battery and the resistors in a circuit			One of the important effects of a resistor is that it converts electrical energy into other forms of energy, such as heat and light. A battery goes flat when all its chemical potential energy has been converted into other forms of energy.
2 hours	Resistors in series	• Know that current is constant through each resistor in series circuit. • Know that series circuits are called voltage dividers because the total potential difference is equal to the sum of the potential differences across all the individual components. • Calculate the equivalent (total) resistance of resistors connected in series using: $R_s = R_1 + R_2 + ...$	**Prescribed experiment:** (Part 1 and part 2) **Part 1** Set up a circuit to show that series circuits are voltage dividers, while current remains constant	**Materials:** Light bulbs, resistors, batteries, switches, connecting leads, ammeters, voltmeters	When resistors are connected in series, they act as obstacles to the flow of charge and so the current through the battery is reduced. The current in the battery is inversely proportional to the resistance.

Time	Topics Grade 10	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
2 hours	Resistors in parallel	• Know that voltage is constant across resistors connected in parallel • Know that a parallel circuit is called a current divider because the total current in the circuit is equal to the sum of the branch currents • Calculate the equivalent (total) resistance of resistors connected in parallel using: $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$	**Prescribed experiment:** **Part 2** Set up a circuit to show that parallel circuits are current dividers, while potential difference remains constant,	**Materials:** Light bulbs, resistors, batteries, switches, connecting leads, ammeters, voltmeters	When resistors are connected in parallel, they open up additional pathways. The current through the battery therefore increases according to the number of branches.
		• Know that for <u>two resistors</u> connected in parallel, the total resistance can be calculated using: $R_p = \frac{product}{sum} = \frac{R_1 R_2}{R_1 + R_2}$			

ASSESSMENT TERM 2	<u>**TERM 2: Prescribed Formal Assessment**</u> 1. Experiment (Physics): Prescribed Physics experiments Part 1 and Part 2: Electric circuits with resistors in series and parallel measuring potential difference and current 2. Midyear Examinations

Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
		• Calculate the induced emf and induced current for situations involving a changing magnetic field using the equation for Faraday's Law: $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$ where ø=BAcosθ is the magnetic flux			
8 HOURS	<u>**Electric circuits**</u>				
4 hours	Ohm's Law	• Determine the relationship between current, voltage and resistance at constant temperature using a simple circuit • State the difference between Ohmic and non-Ohmic conductors, and give an example of each • Solve problems using the mathematical expression of Ohm's Law, R=V/I, for series and parallel circuits	**Recommended experiment for informal assessment** Obtain current and voltage data for a resistor and light bulb and determine which one obeys Ohm's law.	**Materials:** Light bulb, resistor, connecting wires, ammeter and voltmeter	Maximum of four resistors

Time	Topics Grade 11	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
4 hours	Power, Energy	• Define power as the rate at which electrical energy is converted in an electric circuit and is measured in watts (W) • Know that electrical power dissipated in a device is equal to the product of the potential difference across the device and current flowing through it i.e. P=IV • Know that power can also be given by $P=I^2R$ or $P=V^2/R$ • Solve circuit problems involving the concept of power • Know that the electrical energy is given by E=Pt and is measured in joules (J) • Solve problems involving the concept of electrical energy • Know that the kilowatt hour (kWh) refers to the use of 1 kilowatt of electricity for 1 hour • Calculate the cost of electricity usage given the power specifications of the appliances used as well as the duration if the cost of 1 kWh is given	**Experiment/Demonstration:** Investigate the power dissipated in bulbs connected either in series or parallel or both series and parallel	**Materials:** Bulbs, batteries, conducting wires, crocodile clips, bulb-holders, battery holders, ammeters, voltmeters.	Get learners to estimate the cost saving by consuming less electricity by switching off devices. Maximum of four resistors **Note:** Textbooks use both kWh AND kWhr as abbreviations for kilowatt hour.

TERM 3: GRADE 12

GRADE 12 PHYSICS *(ELECTRICITY & MAGNETISM)* TERM 3

Time	Topics Grade 12	Content, Concepts & Skills	Practical Activities	Resource Material	Guidelines for Teachers
4 HOURS	<u>Electric circuits</u>				
4 hours	Internal resistance and series- and parallel networks	• Solve problems involving current, voltage and resistance for circuits containing arrangements of resistors in series and in parallel • State that a real battery has internal resistance • The sum of the voltages across the external circuit plus the voltage across the internal resistance is equal to the emf: $\varepsilon = V_{load} + V_{internal\ resistance}$ or $\varepsilon = IR_{ext} + Ir$ • Solve circuit problems in which the internal resistance of the battery must be considered. • Solve circuit problems, with internal resistance, involving series-parallel networks of resistors	**<u>Prescribed experiment for formal assessment</u>:** (part 1 and part 2) **Part 1** Determine the internal resistance of a battery **Part 2** Set up a series parallel network with known resistor. Determine the equivalent resistance using an ammeter and a voltmeter and compare with the theoretical value **<u>Recommended Practical Investigation for informal assessment:</u>** Set up a series parallel network with an ammeter in each branch and external circuit and voltmeters across each resistor, branch and battery, position switches in each branch and external circuit. Use this circuit to investigate short circuits and open circuits	**Materials:** Battery, connecting wires resistor, voltmeter, ammeter and switch. **Materials:** Battery, connecting wires, several resistors of different values, voltmeter, ammeter and switch. **Materials:** Battery, connecting wires, several resistors of different values, several voltmeters, several ammeter, switches, a length of low resistance wire.	Some books use the term "lost volts" to refer to the difference between the emf and the terminal voltage. The voltage is not "lost", it is across the internal resistance of the battery, but "lost" for use in the external circuit. The internal resistance of the battery can be treated just like another resistor in series in the circuit. The sum of the voltages across the external circuit plus the voltage across the internal resistance is equal to the emf: $\varepsilon = V_{load} + V_{internal\ resistance}$

ADDENDUM M: Secondary Coding to Determine Fluency Between Representational Modes for Physics and Chemistry

Physics

coding 0-3					Representational Mode Coding if received Competence and Fluency Level Code of 3					Combined Representational Mode Code (Level 3)	Representational Mode Coding if received Competence and Fluency Level Code of 2					Combined Representational Mode Code (Level 2)	Overall Representational Mode Code
G (graphical)	E (experimental)	S (symbolic)	NS (non-specialist words)	X (expert words)													
2	2	0	2	1							G	E		NS		GENS	
3	2	0	3	1	G			NS		GNS		E				E	GENS
3	2	0	3	1	G			NS		GNS		E				E	GENS
2	0	0	1	1							G					G	
3	2	0	3	2	G			NS		GNS		E			X	EX	GENSX
3	3	0	2	1	G	E				GE				NS		NS	GENS
1	3	0	2	2		E				E				NS	X	NSX	ENSX
2	2	0	2	1							G	E		NS		GENS	
2	1	0	1	1							G					G	
3	2	0	3	1	G			NS		GNS		E				E	GENS
3	2	1	2	1	G					G		E		NS		ENS	GENS
3	1	0	3	1	G			NS		GNS							
3	3	3	3	2	G	E	S	NS		GESNS					X	X	GESNSX
3	2	0	3	1	G			NS		GNS		E				E	GENS
1	0	0	0	0													
1	2	0	1	1								E				E	
1	1	1	3	1				NS		NS							
3	0	0	2	1	G					G				NS		NS	
0	2	0	2	1								E		NS		ENS	
1	1	0	1	1													
1	1	0	1	0													
2	1	0	2	1							G			NS		GNS	
1	2	0	1	0								E				E	
3	1	2	3	2	G			NS		GNS			S		X	SX	GSNSX
3	1	0	3	3	G			NS	X	GNSX							GNSX
2	2	0	2	1							G	E		NS		GENS	
3	2	3	3	2	G		S	NS		GSNS		E			X	EX	GESNSX
0	2	1	2	1								E		NS		ENS	
3	1	2	3	1	G			NS		GNS			S			S	GSNS
3	1	0	2	1	G					G				NS		NS	
0	1	0	0	0													
2	2	0	3	1				NS		NS	G	E				GE	GENS
3	1	1	3	1	G			NS		GNS							
1	2	0	1	1								E				E	
0	3	0	2	1		E				E				NS		NS	
1	2	0	1	0								E				E	
2	2	0	2	0							G	E		NS		GENS	
0	1	0	1	0													
2	1	1	2	1							G			NS		GNS	
2	2	0	3	1				NS		NS	G	E				GE	GENS
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3	0	0	3	2	G			NS		GNS					X	X	GNSX
0	2	0	2	2								E		NS	X	ENSX	
3	1	0	3	2	G			NS		GNS					X	X	GNSX
2	0	0	2	2							G			NS	X	GNSX	
3	2	0	3	2	G			NS		GNS		E			X	EX	GENSX
2	0	0	3	2				NS		NS	G				X	GX	GNSX
3	1	2	3	2	G			NS		GNS			S		X	SX	GSNSX
2	3	0	3	3		E		NS	X	ENSX	G					G	GENSX
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3	2	0	3	3	G			NS	X	GNSX		E				E	GENSX
2	0	0	2	2							G			NS	X	GNSX	
0	0	0	1	1													
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3	1	0	3	3	G			NS	X	GNSX							GNSX
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2	0	0	2	1							G			NS		GNS	
2	2	0	2	2							G	E		NS	X	GENSX	
1	0	0	2	1										NS		NS	
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2	0	0	3	2				NS		NS	G				X	GX	GNSX
2	0	0	3	1				NS		NS	G					G	
2	3	0	3	1		E		NS		ENS	G					G	GENS
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2	0	0	2	1							G			NS		GNS	
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2	2	0	3	3				NS	X	NSX	G	E				GE	GENSX
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2	1	0	2	2							G			NS	X	GNSX	
2	3	0	3	3		E		NS	X	ENSX	G					G	GENSX
1	2	0	2	1								E		NS		ENS	
2	3	0	3	3		E		NS	X	ENSX	G					G	GENSX
2	3	2	3	2		E		NS		ENS	G		S		X	GSX	GESNSX
2	1	0	3	3				NS	X	NSX	G					G	GNSX
2	0	3	3	2			S	NS		SNS	G				X	GX	GSNSX
																Total codes	43

Chemistry

coding 0-3					Representational Mode Coding if received Competence and Fluency Level Code of 3					Combined Representational Mode Code (Level 3)	Representational Mode Coding if received Competence and Fluency Level Code of 2					Combined Representational Mode Code (Level 2)	Overall Representational Mode Code
G (graphical)	**E** (experimental)	**S** (symbolic)	**NS** (non-specialist words)	**X** (expert words)													
0	1	0	1	1													
0	1	0	2	0										NS		NS	
0	2	0	3	2				NS		NS		E			X	EX	
0	1	0	2	0										NS		NS	
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0	1	0	2	1										NS		NS	
2	3	0	3	2		E		NS		ENS	G				X	GX	**GENSX**
0	3	0	3	1		E		NS		ENS							
0	3	0	2	1		E				E				NS		NS	
0	2	0	2	1								E		NS		ENS	
2	2	0	2	2							G	E		NS	X	GENSX	
2	3	0	3	2		E		NS		ENS	G				X	GX	**GENSX**
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0	3	0	2	2		E				E				NS	X	NSX	**ENSX**
0	2	0	2	0								E		NS		ENS	
0	2	0	1	0								E				E	
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0	1	0	1	1													
1	2	0	2	0								E		NS		ENS	
0	3	0	3	3		E		NS	X	ENSX							**ENSX**
0	1	0	1	1													
0	3	0	3	2		E		NS		ENS					X	X	**ENSX**
0	3	0	3	2		E		NS		ENS					X	X	**ENSX**
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0	1	0	2	0										NS		NS	
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0	2	0	2	0								E		NS		ENS	
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1	2	1	3	2				NS		NS		E			X	EX	**ENSX**
2	2	1	2	2							G	E		NS	X	GENSX	
2	1	2	3	2				NS		NS	G		S		X	GSX	**GSNSX**
3	1	2	3	2	G			NS		GNS			S		X	SX	**GSNSX**
2	2	2	3	2				NS		NS	G	E	S		X	GESX	**GESNSX**
0	2	1	2	1								E		NS		ENS	
1	1	1	2	1										NS		NS	
1	0	2	3	2				NS		NS			S		X	SX	**SNSX**
1	0	0	2	1										NS		NS	
3	0	3	3	2	G		S	NS		GSNS					X	X	**GSNSX**
3	0	3	3	3	G		S	NS	X	GSNSX							**GSNSX**
																Total codes	44